NISTIR 89-4134

QUANTIFICATION OF HEAT LOSSES THROUGH STRUCTURAL SUPPORTS FOR SHALLOW TRENCH HEAT DISTRIBUTION SYSTEMS

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Prepared for:
Tri-Service Building Materials Committee

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ABSTRACT

Shallow trench heat distribution systems generally contain numerous structural supports, which are often in direct contact with hot carrier pipes, form highly conductive heat flow paths, and are major sources of heat loss. Quantification of the heat loss caused by thermal bridges due to pipe supports and prediction of temperature distribustions were achieved by using three finite element computer models. The models considered the two-dimensional, steady-state heat conduction within a rectangular concrete trench containing two insulated pipes with and without pipe supports and the surrounding earth. The theoretical basis, computational scheme, and the data input and outputs of the developed computer programs for sample calculations are described. The two trench pipe support systems studied used horizontal anchoring and vertical supports. The rate of heat loss at the pipe section with structural supports is approximately 17 times greater than at the section without pipe supports. For typical support spacings, slightly more than one half of the total heat loss from the pipes occurs at the supports.

Keywords : Computer program, district heating and cooling, finite element method, heat loss, heat transfer, pipe support system, shallow trench, underground heat distribution system.

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1. Introduction

A central heating and cooling plant with associated distribution systems installed in large institutions and military facilities is potentially more efficient and economical than a number of smaller systems. However, the favorable benefits cannot be realized unless the operating cost due to heat loss through the underground distribution system is low. The shallow trench heat distribution system is considered an alternative to the directly buried conduit system because it has advantages as follows: reduced maintenance and repair costs, easy access for inspection and testing, and relatively dry condition for minimizing possible corrosion problems compared to a direct burial system.

In shallow trench distribution systems, steam or hot water lines are routed through concrete trenches from a central heating plant to the buildings. The transmission heat loss from insulated piping to the surrounding soil consumes a large portion of the fuel energy cost and is one of the major operating expenditures. Piping hangers and supports that penetrate the layers of pipe insulation form highly conductive heat flow paths called thermal bridges and conduct excessive heat from carrier pipes to the surrounding earth. In addition to increased pipe heat losses, the structural supports can contribute to problems with moisture condensation, corrosion, and deterioration of pipe anchoring systems. At present, there are no test procedures or theoretical studies to evaluate the significance of the heat loss effect of these thermal bridges.

Experimental techniques such as field tests for measuring the heat loss from underground pipes are expensive and time consuming. Numerical simulations of physical systems are extensively used for solving heat transfer problems due to the rapid advance in computer technology with increased computing speed and decreasing costs. Mathematical modeling can provide a relatively inexpensive and rapid means for evaluating the performance of the heat distribution system. It also can be used for assessing the effects of various system variables such as pipe size, insulation thickness and operating fluid temperatures. In the design of a new distribution system or improvement of the existing one, mathematical modeling is a valuable tool. Modifications to the design can be implemented and tested numerically without difficulty. The quantification of heat losses associated with pipe supports can provide a basis for the following: calculating the economic pipe insulation thicknesses and the maximum permissible heat loss values, the retrofitting of existing pipelines, and furnishing information required for improved criteria for construction guidance on design and installation of efficient heat distribution systems.

This report presents the procedures to calculate the heat loss and temperature distributions for sections of two insulated pipes installed with and without pipe supports in a concrete trench. The trench pipe support systems studied include the horizontal anchoring and the vertical supports as illustrated in Detail 5 of Guide Specification CEGS-15709 (1). The report also describes the theoretical basis of computer programs which are developed based on the finite element analysis to solve a two-dimensional steady-state heat transfer problem. The program predicts the pipe heat loss and temperature distributions in the vicinity of underground shallow trench systems.

2. Theoretical Basis

A rectangular concrete trench that contains two insulated circular pipes supported by piping anchors, and the surrounding soil involves complex configurations, composite materials, and at least two modes of heat transfer, for example, conduction and convection. It is not possible to obtain closed form analytical solutions for shallow trench heat distribution system using analytical methods. The finite element method is used to deal with this non-linear type of heat transfer problem and to obtain approximate solutions to the governing differential equations. The method can model irregularly shaped geometries more accurately and change the element size more easily than the finite difference method.

The governing differential equation describing the temperature field in a solid continuum, under steady-state conditions with no internal heat generation within the region, may be expressed by the two-dimensional, heat conduction equation as

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y} \right) = 0 \qquad (1)$$

with temperature boundary conditions specified on a part of the boundary:

$$T = T_b \quad ; \quad \text{on } S_1 \qquad (2)$$

and the convective boundary conditions specified on portion of the boundary:

$$k_x \frac{\partial T}{\partial x} l_x + k_y \frac{\partial T}{\partial y} l_y + h\,(T - T_a) = 0 \; ; \; \text{on } S_2 \qquad (3)$$

where T is temperature, k_j is thermal conductivity in the j - direction, x and y are Cartesian coordinates, T_b is the prescribed temperature for the boundary S_1, S_1 is the boundary segment at T_b, S_2 is the boundary segment subject to convective heat transfer, l_x and l_y are direction cosines of a vector perpendicular to S_2, h is the convective heat transfer coefficient, and T_a is the temperature of the external environment.

A solution for the temperature field can be obtained by approximating the unknown temperatures over the element, which is a small, but finite, part of the domain as

$$T(x,y) = [N(x,y)] \{T_i\} \tag{4}$$

where N (x,y) and T_i are the shape functions and temperature at node i, respectively.

Using the approximation represented by equation 4 and the Galerkin weighted residual method [2 - 4], the heat conduction equation can be changed into a system of simultaneous equations, which can be written in matrix form as

$$[K] \{T\} = \{F\} \tag{5}$$

where [K] is the conductance matrix, {T} is the nodal temperature vector, and {F} is the forcing vector.

The typical elements of the matrices and vectors in equation 5 are:

$$K_{ij} = \int_V \left(k_x \frac{\partial N_i}{\partial x} \frac{\partial N_j}{\partial x} + k_y \frac{\partial N_i}{\partial y} \frac{\partial N_j}{\partial y}\right) dV + \int_{S_2} h\, N_i\, N_j\, d\,S \tag{6}$$

$$F_i = \int_{S_2} h\, T_a\, N_i \; dS \tag{7}$$

The global system of equations can be obtained by assemblage of each of these equations for an element and modification of the assembled equations to account for constant temperature and convective heat transfer boundary conditions. For the two-dimensional thermal analysis, three-node triangular elements are used to represent regions enclosed by boundaries of complex shapes of different materials which are found in shallow trench distribution systems. The LU decomposition method [5] is used to solve the global system of linear equations for the unknown temperature vector. In this method, the conductance matrix is decomposed into the form of a product of two matrices: the lower and upper triangular matrices and the resulting set of equations are solved using forward substitution followed by back substitution.

The monthly average earth temperature used as the prescribed temperature boundary conditions for the earth region is dependent upon the site location, month of the year, and the depth below the ground surface, and can be estimated from the following equation [6]:

$$T = T_a + T_b \exp\left(-y\sqrt{w/2\alpha}\right) \sin\left[2\pi(t-3)/12 - y\sqrt{w/2\alpha}\right] \tag{8}$$

where T = the monthly average earth temperature, ^oC (^oF)

T_a = the annual average earth temperature of the site, ^oC (^oF)

T_b = the annual amplitude of the monthly average temperature cycle, oC (^oF)

y = depth from the ground surface, m (ft)

w = angular frequency of the annual cycle, rad/h

α = thermal diffusivity of the soil, m^2/h (ft^2/h)

t = the elapsed time from January, month

Convective heat transfer in the airspace bounded by the trench walls and the outer surfaces of the insulated pipes is treated by assuming an effective conductance for natural convection in the trench. The rate of convective transport can be approximated by an equivalent heat conduction of the form [7,8]:

$$q = K_e \ (T_h - Tc)/L \tag{9}$$

where q = the average heat flow rate, W/m^2 ($Btu/h.ft^2$)

K_e = the effective thermal conductivity of the enclosed air layer, W/m.K (Btu/h.ft.^oF)

T_h = the temperature of the hot surface, ^oC (^oF)

T_c = the temperature of the cold surface, ^oC (^oF)

L = the characteristic thickness of air layer, m (ft)

An effective thermal conductivity is used to modify the conduction solution to account for natural convection in air confined between a pair of heated pipes and the cooler enclosure walls. The ratio of the effective to the actual thermal conductivity of the enclosed airspace is a function of the Rayleigh number based on the characteristic dimension or the thickness of the air layer and on the temperature difference of the hot and cold surfaces [7].

Two-dimensional natural convection heat transfer from two heated isothermal horizontal cylinders to an isothermal-cooled rectangular enclosure was recently studied experimentally by Stewart and Verhulst [9]. Their experiments were designed to simulate the heat transfer encountered in underground heat distribution systems where steam and condensate lines are routed through utility corridors (utilidors) from a central plant. Two copper cylinders were used to simulate the steam supply and condensate return lines. The fluid between the cylinders and the enclosure was distilled water to simulate the Rayleigh number range encountered with air in air in actual utilidors. Their experimental data were correlated based on a hypothetical gap width L, as described below:

$$Nu = 0.420\, R_a^{\;0.219} \tag{10}$$

where Nu = Nusselt number, $h\,L/k_f = k_e/k_f$

R_a = Rayleigh number, PrGr

h = average heat transfer coefficient

L = hypothetical gap width, $L=R_o-R_i$

k_f = thermal conductivity of fluid at T_f

Pr = Prandtl number, ν/α

ν = kinematic viscosity

Gr = Grashof number, $g\beta\,(T_i-T_o)\,L^3/\nu^2$

β = thermal expansion coefficient at T_f

T_i = effective cylinder surface temperature

= $(R_s\,T_s + R_l T_l)/(R_s + R_l)$

R_s, R_l = radius of small and large cylinder, respectively

T_s, T_l = temperature of small and large cylinder, respectively

g = acceleration of gravity

T_o = surface temperature of the enclosure

R_o = effective radius of the rectangular enclosure, which is defined as the radius of a cylinder having the same perimeter length as the enclosure.

R_i = effective radius of the insulated pipes, which is defined as the radius of a cylinder having the perimeter equal to the total perimeter of the pipes.

The effect of radiant exchange between the pipes and trench walls to pipe heat losses is assumed to be negligible due to the low emissivity of the aluminum jacket surface. For an insulated piping system, the surface film resistance between the hot fluid and the pipe, the thermal resistance of pipe wall, and that of the metal jacket can generally be ignored in comparison to the thermal resistance of the insulation.

The rate of heat loss from an insulated pipe with no pipe support can be obtained using the following equation, which is derived based on one-dimensional, steady-state, radial heat conduction in a composite pipe, along with the calculated value of average temperature drop across the pipe insulation layer:

$$q = \frac{2 \pi k_i (T_o - T_i)}{\ln (r_o/r_i)} \qquad (11)$$

where q = the heat loss rate per unit length of the insulated pipe, W/m (Btu/h.ft)

k_i = thermal conductivity of insulation material, W/m.K (Btu.in/h.ft^2.F)

y_o = outside radius of the insulation layer, m (ft)

r_i = inside radius of the insulation layer, m (ft)

T_o = the surface temperature of the insulation layer at inner radius r_i, which is assumed to be the same as the working fluid temperature, ^oC (^oF)

T_i = the surface temperature of the insulation layer at outer radius ^oC (^oF)

The heat loss rate per unit length of an insulated pipe having a pipe support is equal to the rate of heat loss through the pipe insulation layer plus the heat loss through the pipe support, and is expressed by

$$q = [k_i\ (2\pi-\phi)\ (T_i - T_o) + k_s\ \phi\ (T_c - T_e)]/\ln\ (r_o/r_i) \qquad (12)$$

where $\phi = 2 \sin^{-1} (t/2r_i)$, radians

t = the stem thickness of the pipe support, m (ft)

k_s = thermal conductivity of pipe support, W/m.K (Btu.in/h. ft^2 .F)

T_c and T_e = the average surface temperature of the pipe support at inner and outer radii r_i and r_o, respectively.

To obtain more realistic prediction of the pipe heat losses, especially at higher pipe fluid temperature, the thermal conductivity of calcium silicate is stored, as a function of its mean temperature [10], in a computer subprogram. The thermal conductivity function is based on a look-up table that provides the temperature dependent thermal conductivity value for pipe insulation.

3. Description of the Computer Programs

A finite element computer program called UHDS, has been developed to model two-dimensional, steady-state heat conduction involving a section of insulated pipes with no pipe supports. This computer program is written in FORTRAN language and consists of a main program and nine subroutines. The main program reads in the input data, initializes the necessary matrices, vectors and scalars, calls pertinent subroutines, performs calculations of the conductance matrix and excitation vector modified to account for convection and constant temperature boundary conditions, and prints out the calculated nodal temperatures.

Subroutine PIPEN is used to read in concrete trench and piping geometry, echos the data to allow the checking of input data, and calculates rectangular coordinates for each nodal point of the two-pipe system. Subroutine TGO calculates the average undisturbed earth temperatures at various depths for the month of interest. Subroutines INSULK and SOILK provide the insulation and soil thermal conductivity values, respectively, for various insulation and earth temperatures by linear interpolation of sets of thermal conductivity versus mean temperature data. Subprograms TGXX furnishes the external boundary temperatures of the outer earth region surrounding the shallow trench and TWOPIP determines the rate of heat loss from two insulated buried pipes to the ground. Subroutines EQUIK calculates the equivalent thermal conductivity of airspace surrounding the pipes in a concrete trench and SOLVE is used to solve system of simultaneous equations by LU decomposition method [5]. Subroutine PIPEHL computes the temperature drops across the pipe insulation layers and the heat loss rates from both underground pipes, and prints out the results of these calculations.

Two computer programs called UHDSV and UHDSH similar to the computer code UHDS in program design and flow control structures, have been developed using three-node linear triangular elements to perform heat loss analysis of shallow trench heat distribution systems with vertical pipe supports and horizontal anchoring. A listing of the source codes of these computer programs is given in Appendix B.

4. Sample Calculations

The heat distribution system modeled numerically consists of a 152 mm (6 in.) steam pipe and a 76 mm (3 in.) condensate return pipe installed side by side in a 1.22 m (4 ft) wide by 1.25m (4 ft. 1 in.) high concrete trench with an inner dimension of 0.91 m (3 ft) by 0.81 m (2 ft. 8 in.) high. The concrete shallow trench has 230 mm (9 in.) thick trench cover with its top placed flush with the ground level, 152 mm (6 in.) thick trench walls, and 203 mm (8 in.) thick floor. The thicknesses of pipe insulation (calcium silicate) used for the heat supply and return pipe are 89 mm (3.5 in.) and 64 mm (2.5 in), respectively. The steam and condensate pipes are located at 0.65 m (2 ft. 2 in.) and 0.69 m (2 ft. 3 in.) below the ground surface, respectively, and separated by a distance of 0.45 m (1 ft. 6 in.) between pipe centers. The concrete trench system is surrounded by earth having a thermal conductivity of 2.16 W/m.k (15 Btu.in/h.ft^2 F) and an annual average temperature of 13^o C (56 ^{o}F). Numerical calculations are made for trench pipes installed with and without piping supports based on a 196 ^{o}C

(385 ^{o}F) supply and a 99^{o}C (210 ^{o}F) return temperature. Two trench pipe support systems studied include horizontal anchoring and vertical support as shown in Figure 1, which is depicted from Detail 5 of Guide Specification CEGS-15709 [1]. In the horizontal anchoring system, the insulated pipes are secured through a short section of steel plates to two pieces of wall plates imbedded within the concrete walls. In the vertical support system, both pipes are supported by a short section of structural tees laid on a base plate, which is welded to steel wall plates studded to trench walls. The effects of stud anchors imbedded within concrete walls are neglected in pipe heat loss calculations due to smaller sizes compared to wall plates.

In using the computer programs, the underground heat distribution systems to be modeled numerically are first divided into regions of interest, which include a rectangular concrete trench, pipe insulation covering the carrier pipes, airspace in the concrete trench, outer earth region surrounding the concrete trench, and the piping support system. These regions are then discretized into triangular elements. During this discretization step, the smaller element sizes are used in the areas of anticipated higher temperature gradients and the larger elements employed in the areas of smaller temperature gradients to increase the degree of accuracy. In labeling of nodal points, the nodes along the outer boundaries with the specified temperatures and convective heat fluxes are numbered first to obtain a reduced number of simultaneous equations to be solved for the unknown nodal temperatures.

Figures 2 to 5 show the finite element design for sections of insulated pipes with and without structural supports for steam distribution systems.

These figures are divided into three sets; the "a" figures show the underground system containing trench pipes having vertical pipe supports, the "b" figures illustrate the distribution system involving pipes supported by piping anchors, and the "c" figures show the trench system containing a section of pipes with no pipe supports. Figures 2.a to 2.c show the triangular element mesh for concrete trench wall, floor and cover, and wall plates imbedded in concrete walls. The finite element grid for pipe insulation and pipe supports connected to carrier pipes are shown in Figures 3.a to 3.c. Figures 4.a to 4.c illustrate the mesh for the airspace between the insulated pipes and the trench walls, and structural supports. Figures 5.a b and 2.c show the triangular element mesh for the outer boundary earth region. The finite element grid implemented in the computer programs consists of 226 triangular elements and 132 nodal points for program UHDSV, 204 elements and 121 nodes for UHDSH, and 168 elements and 101 nodes for UHDS, respectively. Table 1 presents a summary of finite element meshes representing regions of the major components of steam distribution systems containing trench pipes with and without piping supports.

Two input data files, for example DATAV1 and DATAV2 for program UHDSV, are created prior to execution of the computer program. The input data files and the outputs from the developed computer programs are given in Appendix A. As shown in Appendix A.1, the DATAV1 file (see the main program and subroutines PIPEV and TGO for data input) contains the title of the computer run, total numbers of nodal points and triangular elements, data for run control parameters, the month of interest, the thermal conductivity and dimensions of the concrete trench, the estimated trench air temperature, the pipe fluid temperatures, the thermal conductivities of pipe insulation and structural supports, the pipe sizes, the insulation thicknesses, the locations of the pipe centers, the thermal properties and dimensions of the earth region, the dimensions of pipe supports, the base plate and wall plates, and the annual average earth temperature and amplitude of the monthly temperature cycle for the site involved. The element data file DATAV2 shown in Appendix A.2 consists of the element number, the node numbers for its three vertices and the material type for each triangular element, total number of elements subject to convection boundary, the element number, the surface convection coefficients for three sides of each element that experiences convection loss.

The boundary conditions include the constant temperatures around the outer surfaces of the steel pipes, the undisturbed earth temperatures along the outermost perimeter of the earth region, and convective heat transfer between the ground surface in the vicinity of the concrete trench and the ambient air. The system of matrix equations is solved for the unknown nodal temperatures using the LU decomposition technique. In order to adjust the insulation and soil thermal conductivities to account for temperature effect, an iterative procedure is used until the heat loss from the trench pipes reaches a steady-state condition.

The system heat loss calculations were carried out on the main-frame Cyber 855 computer at NIST. These calculations required 4 to 8 seconds of execution time. The outputs from the computer program included: pipe heat loss rates, average temperature drops across pipe insulation layers, the resultant temperature at each nodal point, equivalent thermal conductivity of air space, and cartesian coordinates of all nodes based on the predesigned finite element mesh for the heat distribution system involved. A listing of output file OTFILEV from program UHDSV for the sample case is given in Appendix A.7. Table 2 summarizes the results of computer calculations. For the sample case involving pipe fluid temperatures of 196°C (385 °F) and 99°C (210°F), a section of pipes having pipe supports gave approximately 17 times greater total heat loss compared to a pipe section with no pipe supports. The pipes with vertical pipe supports had slightly less heat lost to the trench air, concrete walls, and surrounding earth than those supported by horizontal anchoring. The pipes with piping supports also gave smaller temperature drops across the pipe insulation in comparison to the pipes without pipe supports due to the discontinuity of insulation caused by penetration of highly conductive pipe supports. To determine the effect of pipe fluid temperatures on the heat loss of the shallow trench system, computer calculations were performed for the temperatures of steam supply and condensate return lines of 204 °C (400°F) and 107°C (225 °F), respectively. The calculated results are listed in parenthesis shown in Table 2. As expected, the rate of heat loss from an insulated pipe increases with increasing the pipe working fluid temperature since the convection loss from the pipe to the trench air and the conduction loss through structural supports are directly proportional to the temperature difference between the outer surface of the pipe and the surrounding air or concrete walls.

The effects of pipe supports on the total heat loss from trench pipes are described in Table 3. It is assumed that the span between supports of nominal 150 mm (6 in.) and 75 mm (3 in.) pipes is 4.57 m (15 ft) and the section of piping supports has 0.31 m (1 ft) in length. The heat losses through vertical supports and horizontal anchoring are found to represent 53.6 percent and 55.5 percent, respectively, of the total heat loss from the pipes.

5. CONCLUSIONS

The heat losses and thermal fields of a section of two insulated pipes installed with and without pipe supports in a shallow trench underground heat distribution system were calculated using the computer simulation programs developed based on the finite element method. General formulation of the pertinent governing heat flow equations and boundary conditions, and the solution procedures for a two-dimensional, steady-state heat conduction problem are presented. The computational scheme and the input data required for executing the computer programs are described, and the outputs from the simulation programs for sample cases are presented. Finite element numerical modeling is found to be ideally suited for thermal analysis of concrete trench heat distribution systems involving complex configuration, multi-materials, irregularly shaped boundaries, and different modes of heat transfer.

The calculated results from numerical modeling indicated that the pipe supports increased the pipe heat loss by approximately 17 times relative to the same section of insulated pipes with no pipe supports. For typical support spacings, it is found that approximately 54 to 56 percent of total heat loss from trench pipes occurs at two pipe support systems, which are illustrated in Guide Specification CEGS-15709. Field data on pipe heat loss and temperature distributions of trench air, concrete walls, and soil in the vicinity of the underground systems are needed for validation of the predictive methods.

6. Acknowledgement

This investigation was conducted under the Tri-Service Building Materials Investigational Program and was jointly sponsored by the Headquarters, U. S. Army Corps of Engineers; U.S. Navy, Naval Facilities Engineering Command; and the Headquarters, U.S. Air Force, Engineering and Services.

7. References

1. U. S. Army Corps of Engineers, Guide Specification Military Construction, 'Heat Distribution Systems Outside of Buildings Concrete Shallow Trench Systems', CECS-15709, November 1983.
2. Zienkiewicz, O. C. The Finite Element Method, Third Edition, McGraw-Hill, New York, N. Y., 1977.
3. Dhatt, G. and G. Touzot, The Finite Element Method Displayed, John Wiley and Sons, New York, N. Y., 1984.
4. Jaluria, Y. and K. E. Torrance, Computational Heat Transfer, Hemisphere Publishing, Washington, D. C., 1986.
5. Press, W. H., B. P. Flannery, S. A. Teukolsky and W. T. Vetterling, Numerical Recipes: The Art of Scientific Computing, Cambridge University Press, New York, N. Y., 1986.
6. Kusuda, T. and P. R. Achenbach, "Earth Temperature and Thermal Diffusivity at Selected Stations in the United States", ASHRAE Transactions, Vol. 71, Part I, pp. 61-75, (1965).
7. Eckert, E. R. 6. and R. M. Drake, Analysis of Heat and Mass Transfer, McGraw-Hill, New York, New York, N. Y., 1972.
8. Holman, J. P. Heat Transfer, Fourth Edition, McGraw-Hill, New York, N. Y., 1976.
9. Stewart, W. E. and J. L. Verhulst, "Experimental Free Convection from Piping in District Heating Utilidors", Journal of Energy Resources Technology, Vol. 108, 173-178, (1986).
10. U. S. Department of Energy, Economic Thickness for Industrial Insulation, Fairmont Press, Atlanta, GA, 1983.

Table 1. A Summary of Finite Element Meshes for Steam Distribution Systems With and Without Piping Supports

	Pipes with Vertical Piping Supports	Pipes with Horizontal Piping Supports	Pipes without Piping Support
1. Rectangular Concrete Trench	Elements 1 through 38 (Fig. 2.a)	Elements 1 through 38 (Fig. 2.b)	Elements 1 through 32 (Fig. 2.c)
2. Outer Earth Region	Elements 39 through 80 (Fig. 5.ab)	Elements 39 through 80 (Fig. 5.ab)	Elements 33 through 74 (Fig. 2.c)
3. Pipe Insulation	Elements 81 through 112 (Fig. 3.a)	Elements 81 through 112 (Fig. 3.b)	Elements 75 through 106 (Fig. 3.c)
4. Airspace in Concrete Trench	Elements 113 through 182 (Fig. 4.a)	Elements 113 through 182 (Fig. 4.b)	Element 107 through 168 (Fig.4.c)
5. Piping Support System:			
Steel Supports & Base Plate	Elements 183 through 218 (Figs. 3.a & 4.a)	Elements 183 through 196 (Figs. 3.b & 4.b)	
Steel Wall Plates	Elements 219 through 226 (Fig. 2.a)	Elements 197 through 204 (Fig. 2.b)	

Table 2. A Summary of Calculated Results for Different Pipe Fluid Temperatures

	Pipes with Piping Supports		Pipes without Piping Supports
	Vertical	Horizontal	
1. Heat Loss Rates (Btu/h·ft)			
Pipe No. 1	1678 (1739)	1404 (1465)	92 (97)
Pipe No. 2	262 (324)	688 (759)	28 (31)
Total	1940 (2063)	2092 (2224)	120 (128)
2. Average Temperature Drops across Insulation (F):			
Pipe No. 1	208 (216)	213 (222)	283 (295)
Pipe No. 2	42 (49)	63 (71)	120 (132)
3. Equivalent Thermal Conductivity of Air Space (Btu·in/h·ft^2·F):	6.1 (6.2)	5.9 (6.0)	5.3 (5.3)

Note: Case 1: The fluid temperatures for pipe numbers 1 and 2 are 385° F and 210° F, respectively.

Case 2: The pipe numbers 1 and 2 carried the fluids at 400° F and 225° F, respectively. The calculated results are in parentheses.

Table 3. Effects of Pipe Supports on Pipe Heat Losses

The span between supports of nominal 6-inch and 3-inch pipes is assumed to be 15 ft, and the section of pipes installed with piping supports has 1 ft in length.

The heat loss through a 14 ft long section of pipes without pipes supports is equal to

$$120 \text{ Btu/h·ft} \times 14 \text{ ft} = 1680 \text{ Btu/h}$$

The heat loss from a 1 ft long section of pipes installed with horizontal anchoring system is

$$2092 \text{ Btu/h·ft} \times 1 \text{ ft} = 2092 \text{ Btu/h}$$

The heat loss due to a 1 ft section having vertical supports is equal to

$$1940 \text{ Btu/h·ft} \times 1 \text{ ft} = 1940 \text{ Btu/h}$$

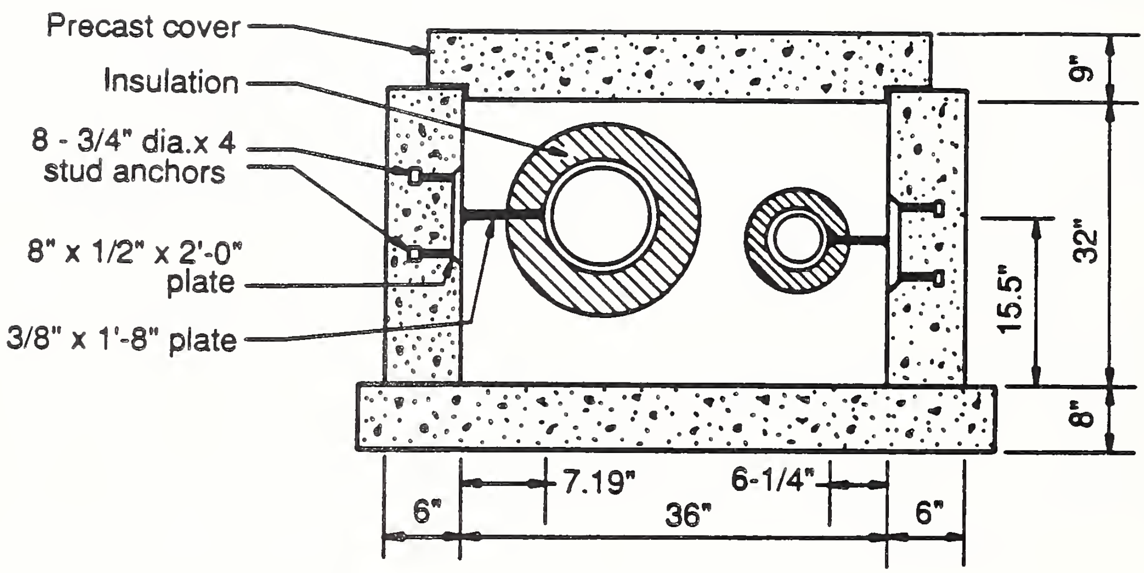
The heat loss through the pipe supports expressed as the percentage of the total heat loss from the pipes, can be calculated as

(i) Horizontal anchoring

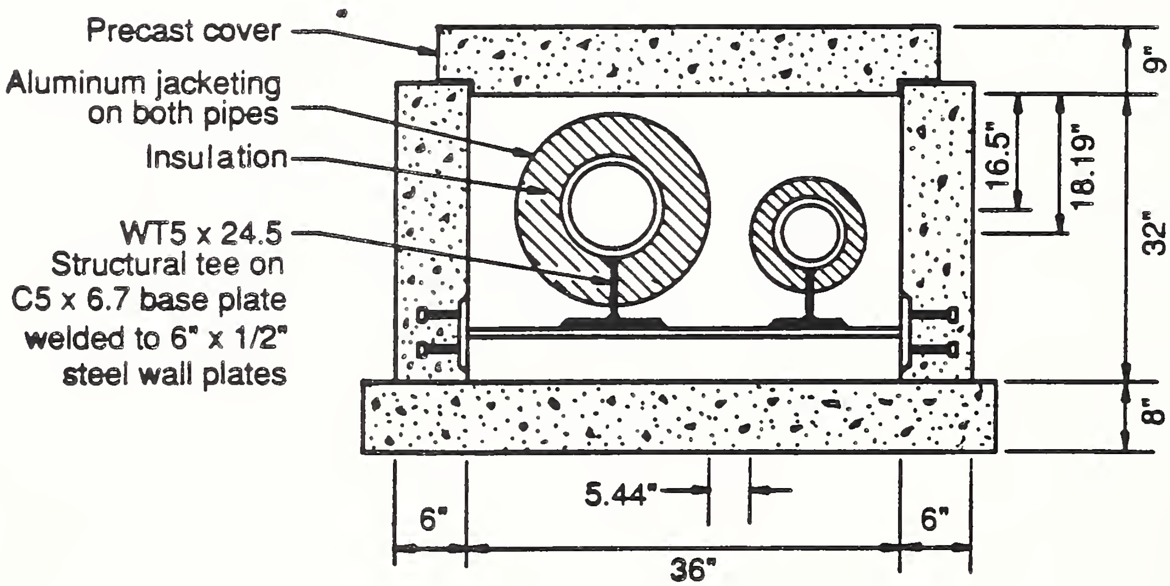
$$\text{\% of total} = \frac{2092}{(1680 + 2092)} \times 100 = 55.5 \text{ \%}$$

(ii) Vertical supports

$$\text{\% of total} = \frac{1940}{(1680 + 1940)} \times 100 = 53.6 \text{ \%}$$



(a) Trench pipe anchor



(b) Trench pipe support

Figure 1. Concrete Shallow Trench Heat Distribution Systems with Pipe Anchoring and Support

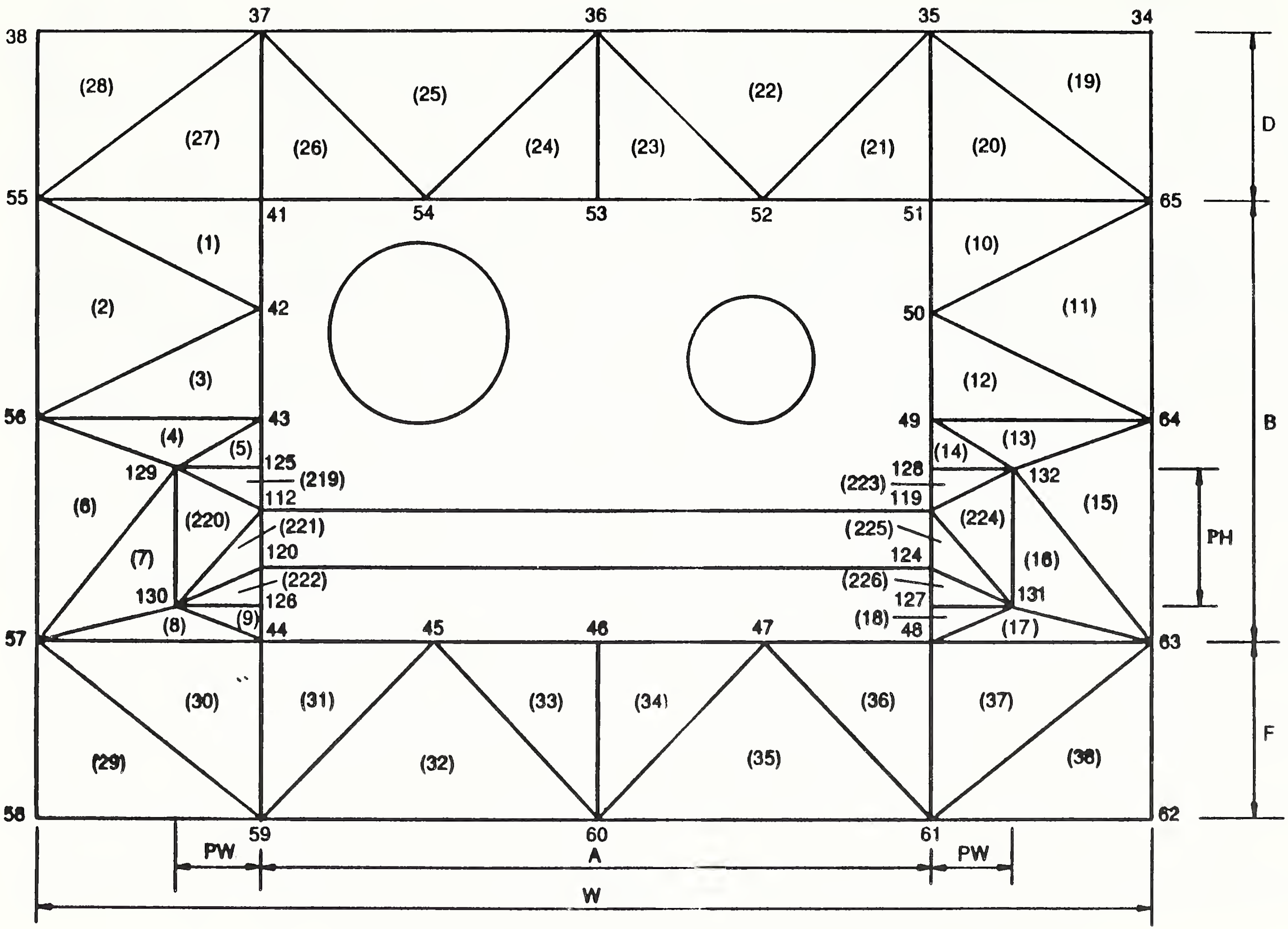


Figure 2.a Finite Element Design for Concrete Trench Walls, Floor and Cover, and Wall Plates for Vertical Piping Supports

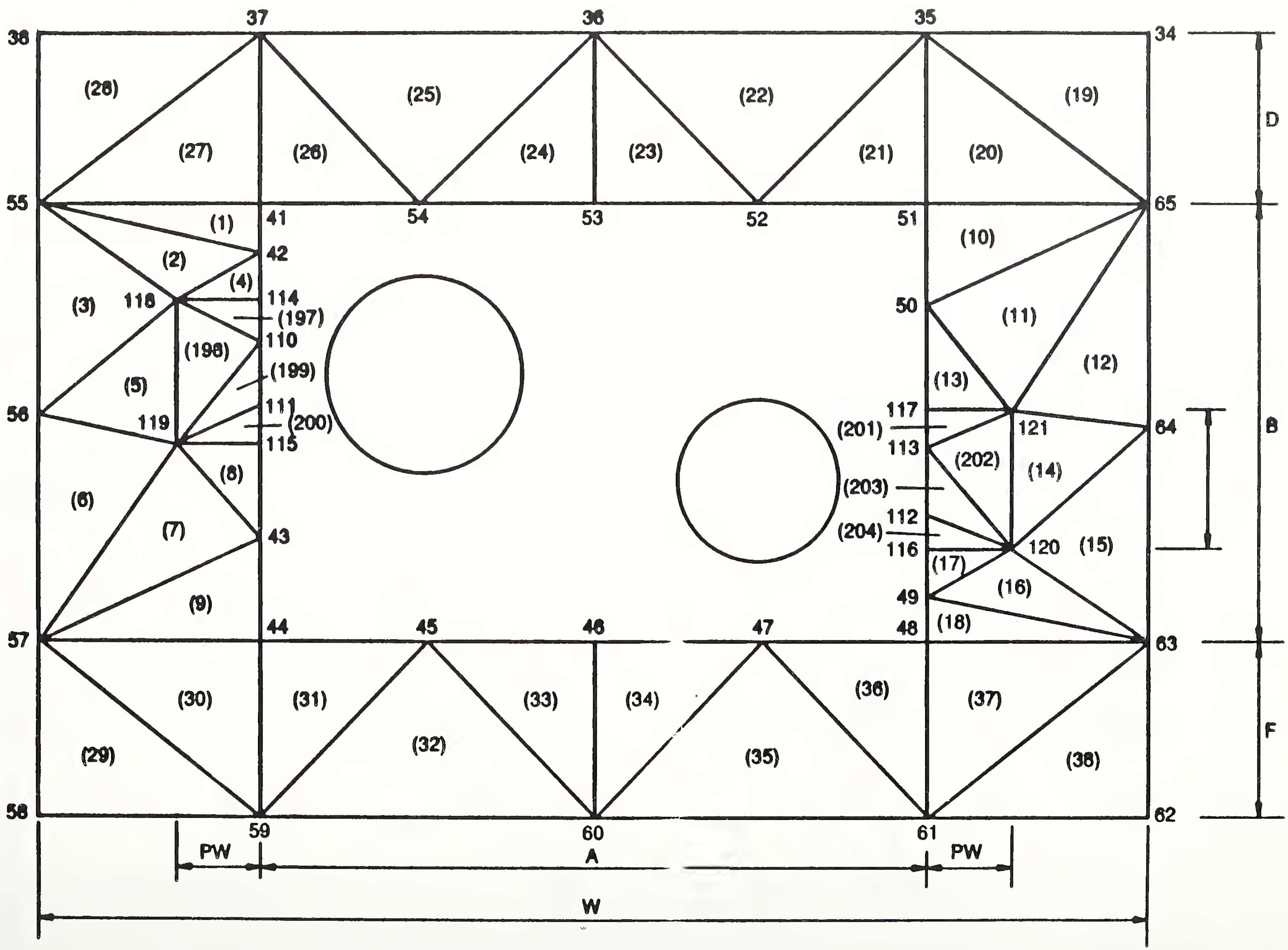


Figure 2.b Finite Element Design for Concrete Trench Walls, Floor and Cover, and Wall Plates for Horizontal Piping Supports

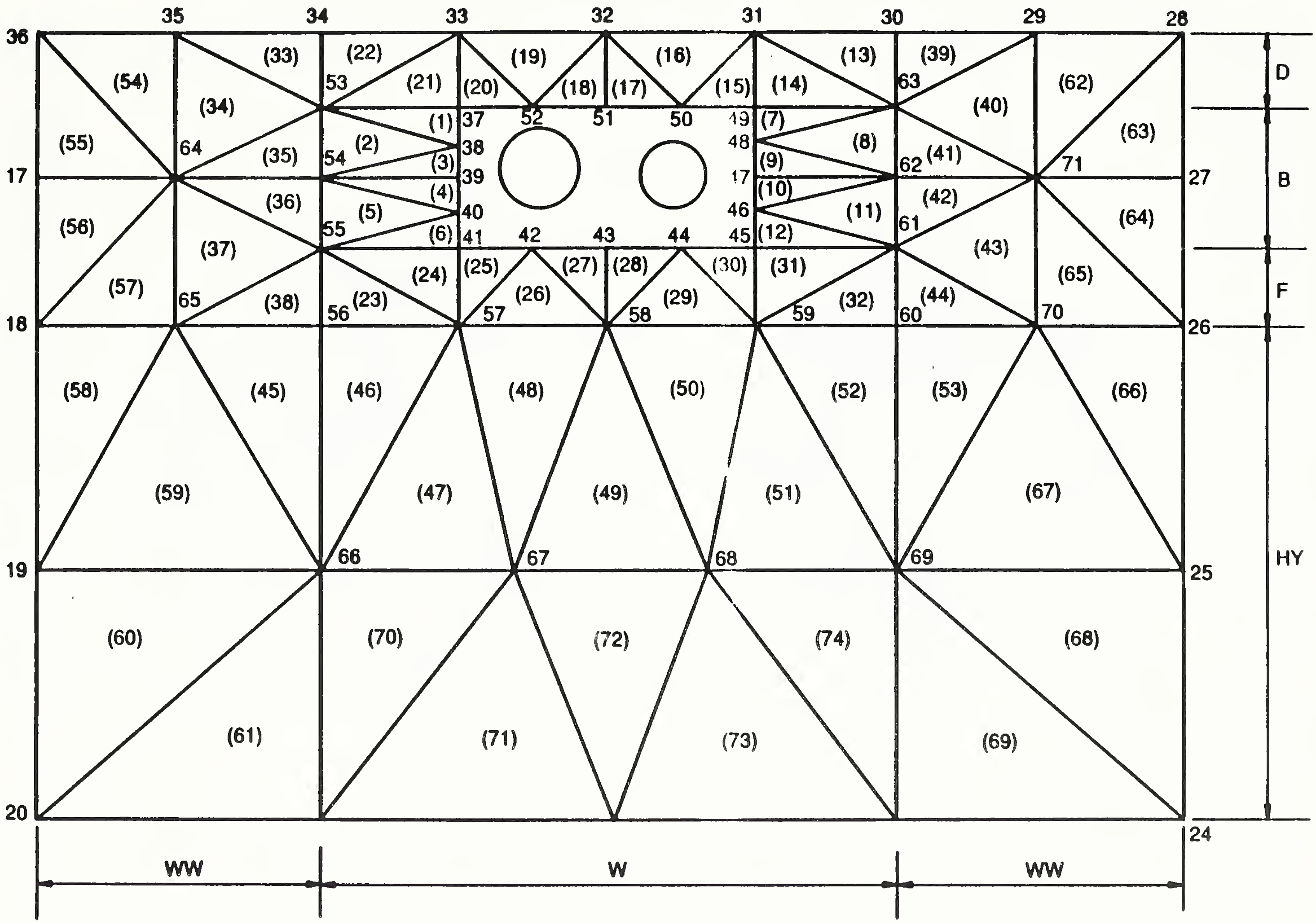


Figure 2.c Finite Element Design for Concrete Trench Walls, Floor and Cover, and Wall Plates for Horizontal Piping Supports

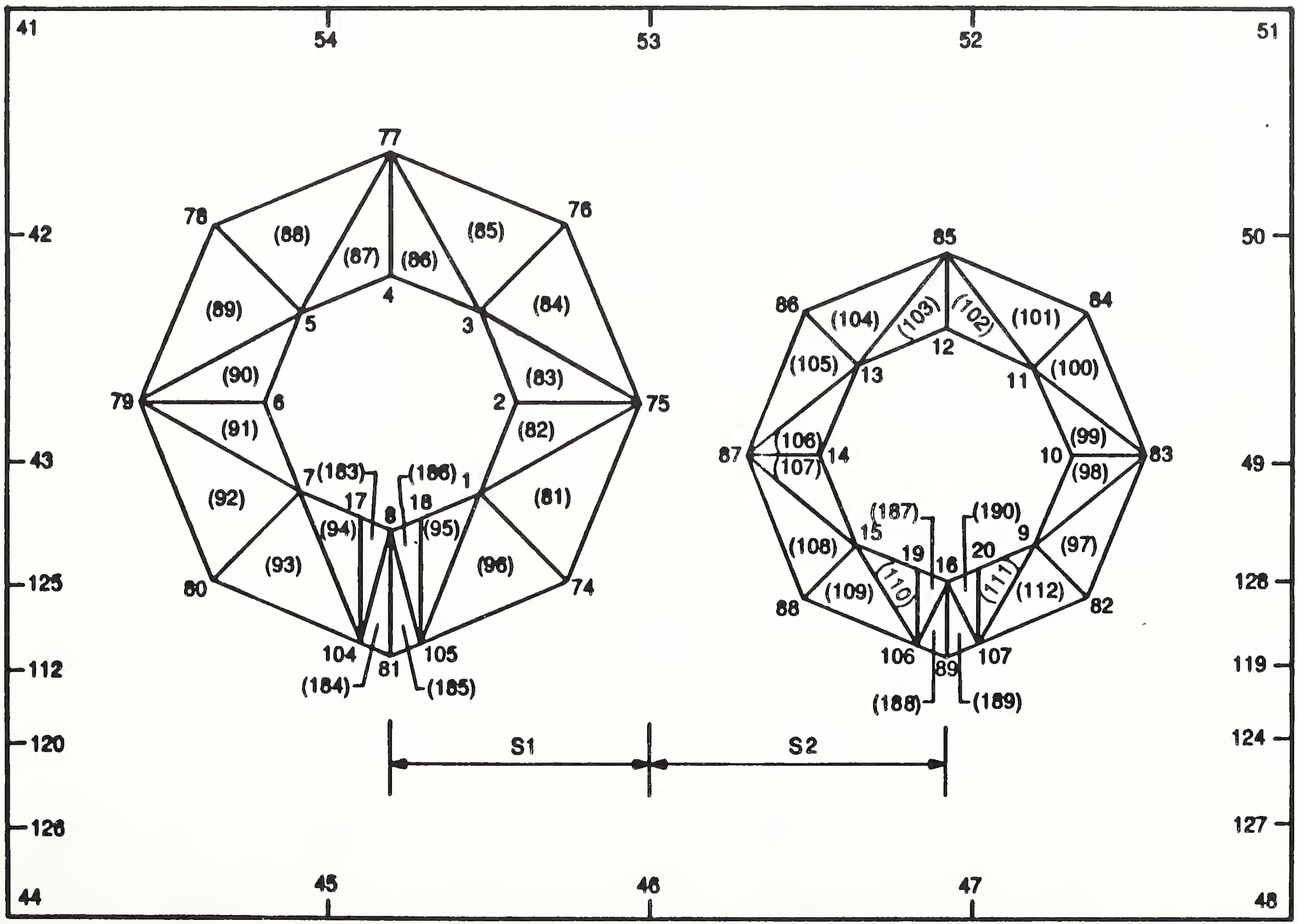


Figure 3.a Finite Element Design for the Pipe Insulation and the Vertical Piping Supports

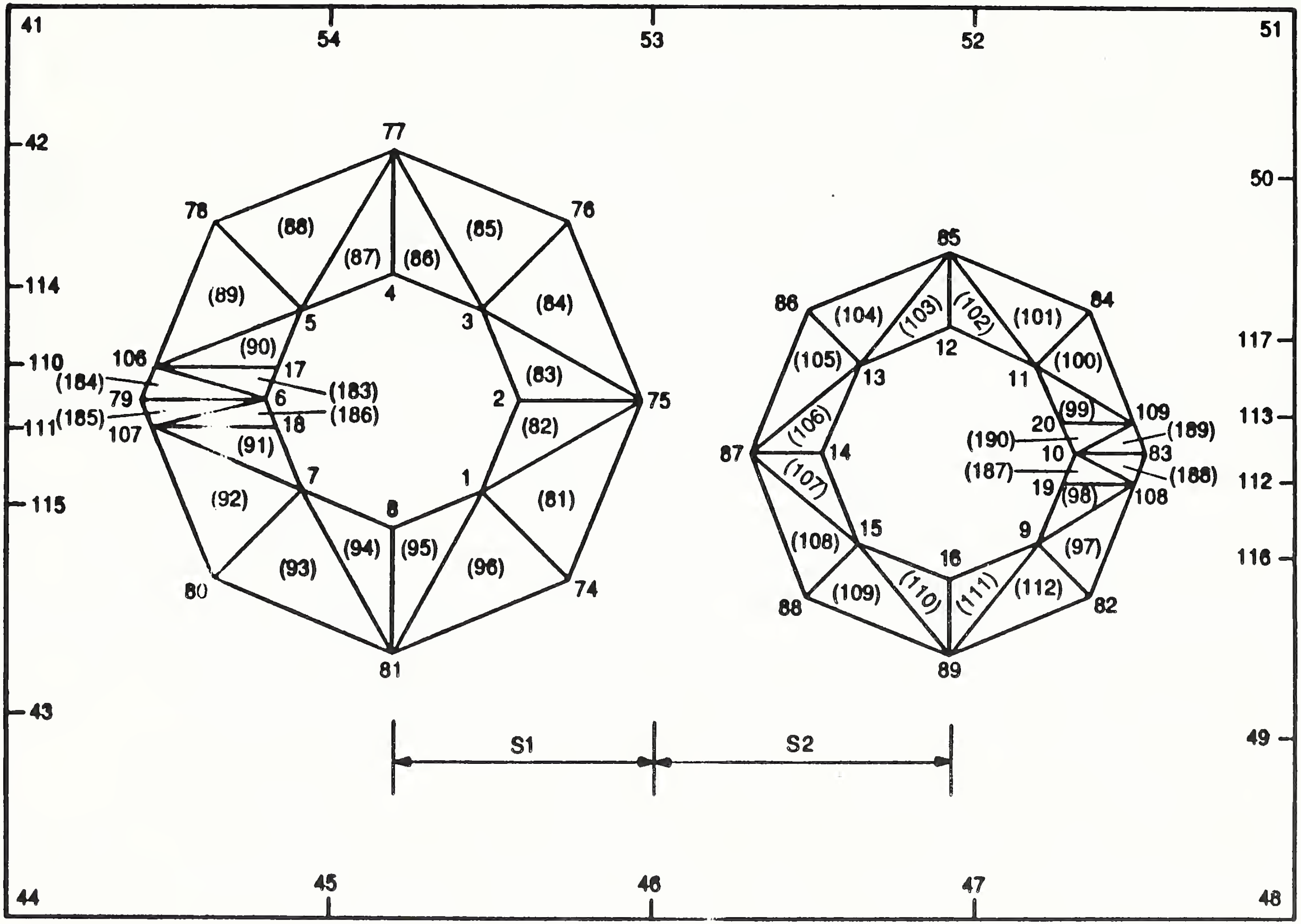


Figure 3.b Finite Element Design for the Pipe Insulation and the Horizontal Piping Supports

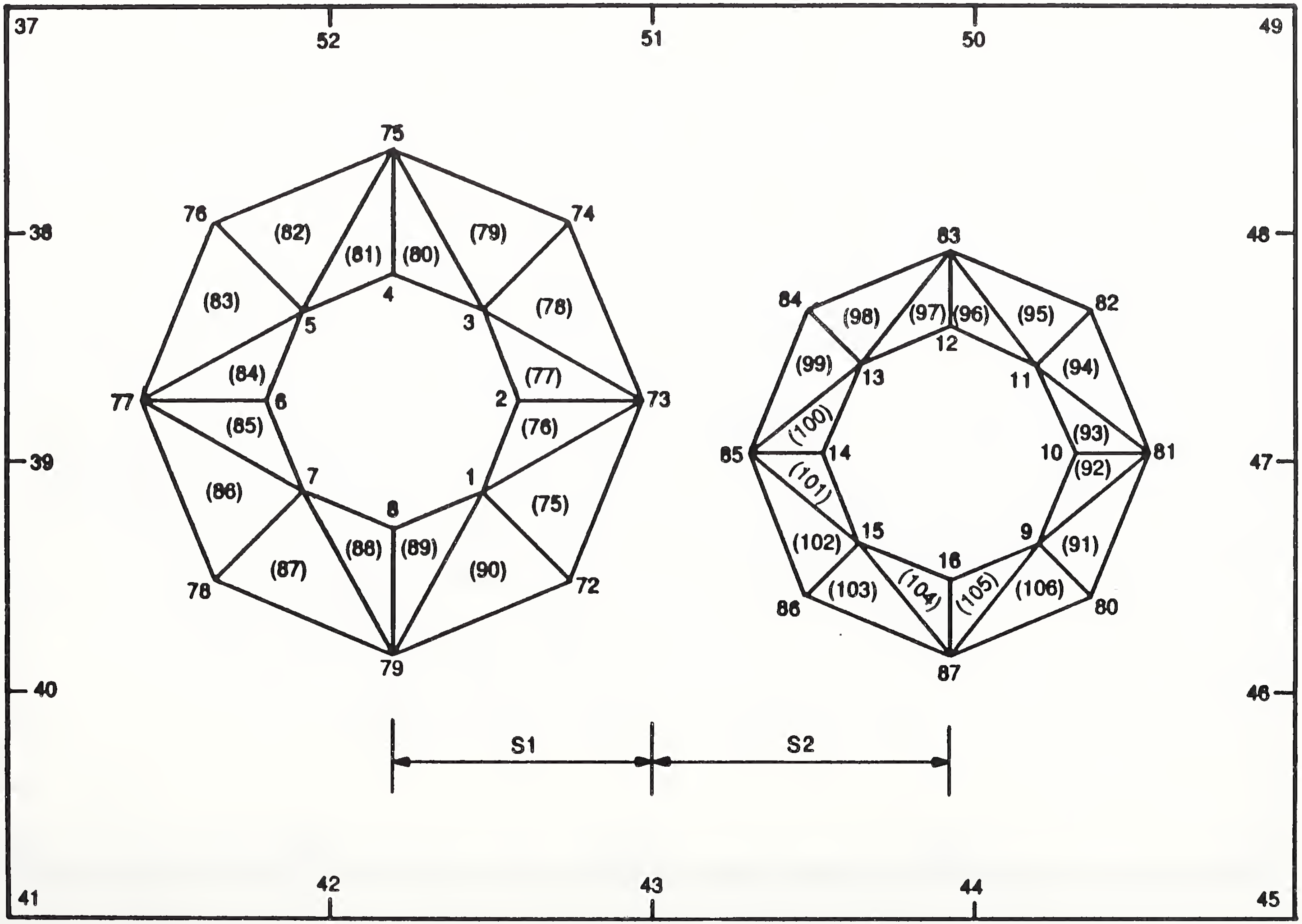


Figure 3.c Finite Element Design for the Pipe Insulation in Pipe Section Without Structural Supports

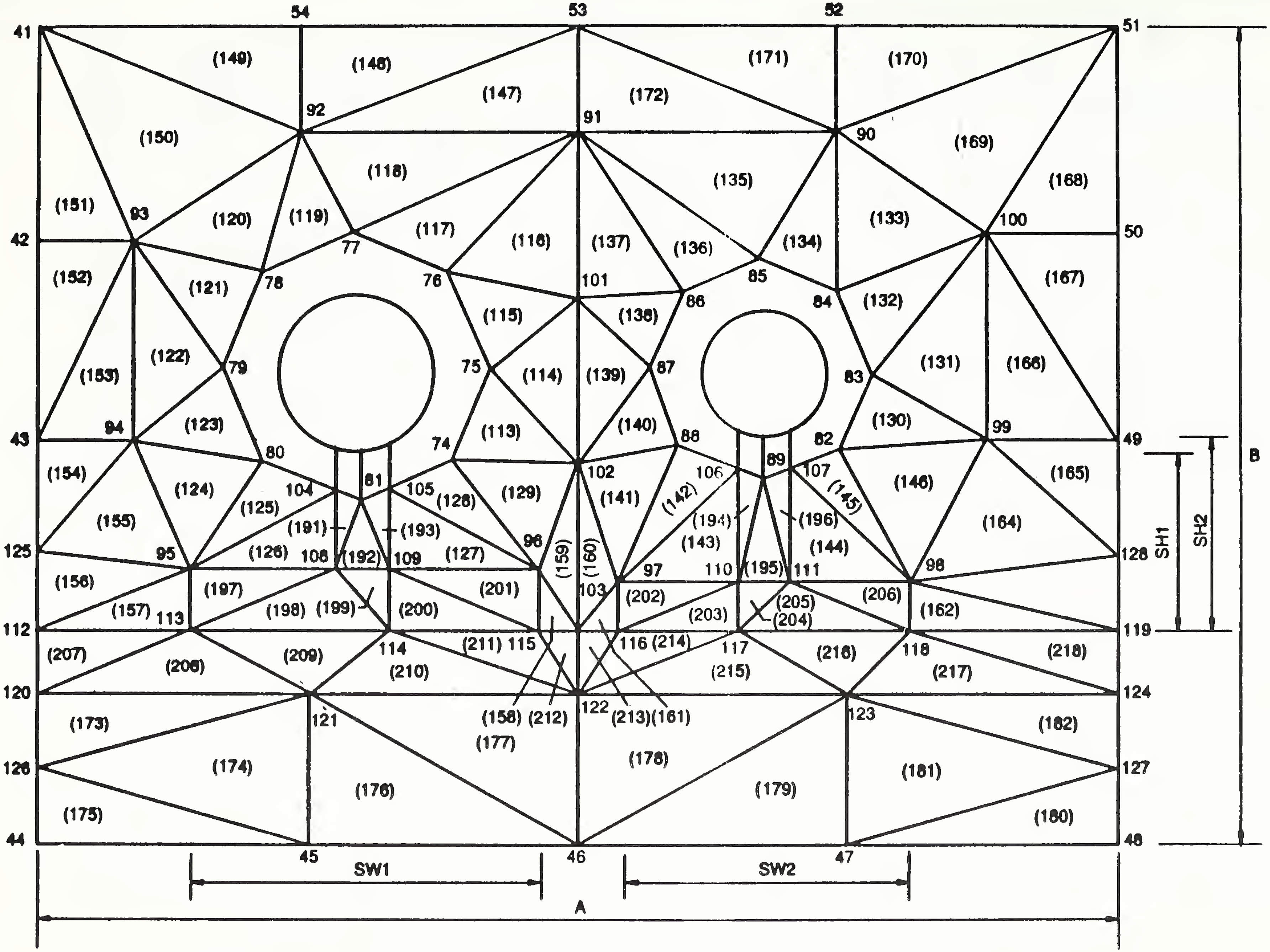


Figure 4.a Finite Element Design for Air Space surrounding the Pipes and Vertical Piping Supports

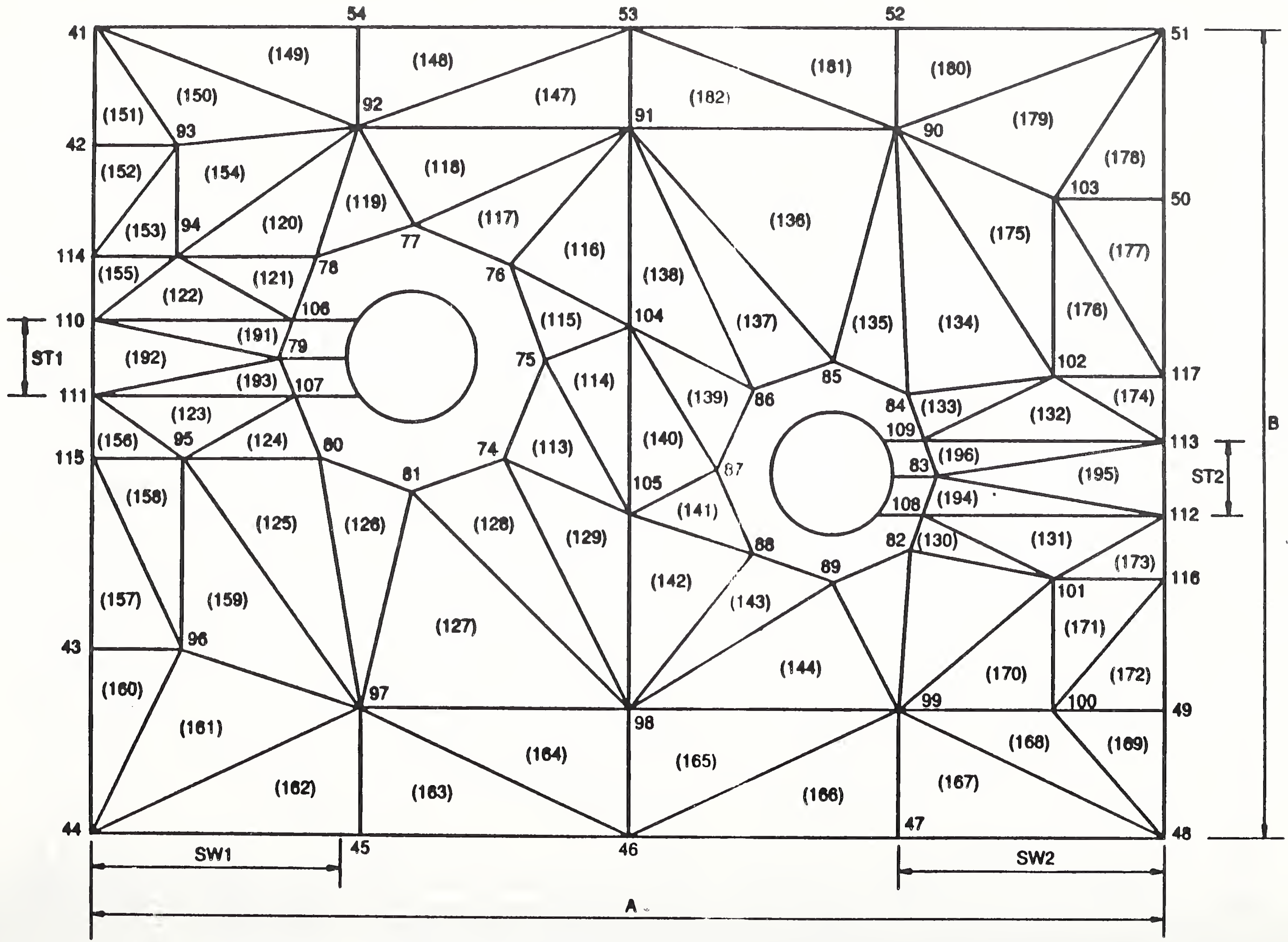


Figure 4.b Finite Element Design for Air Space Surrounding the Pipes and Horizontal Piping Supports

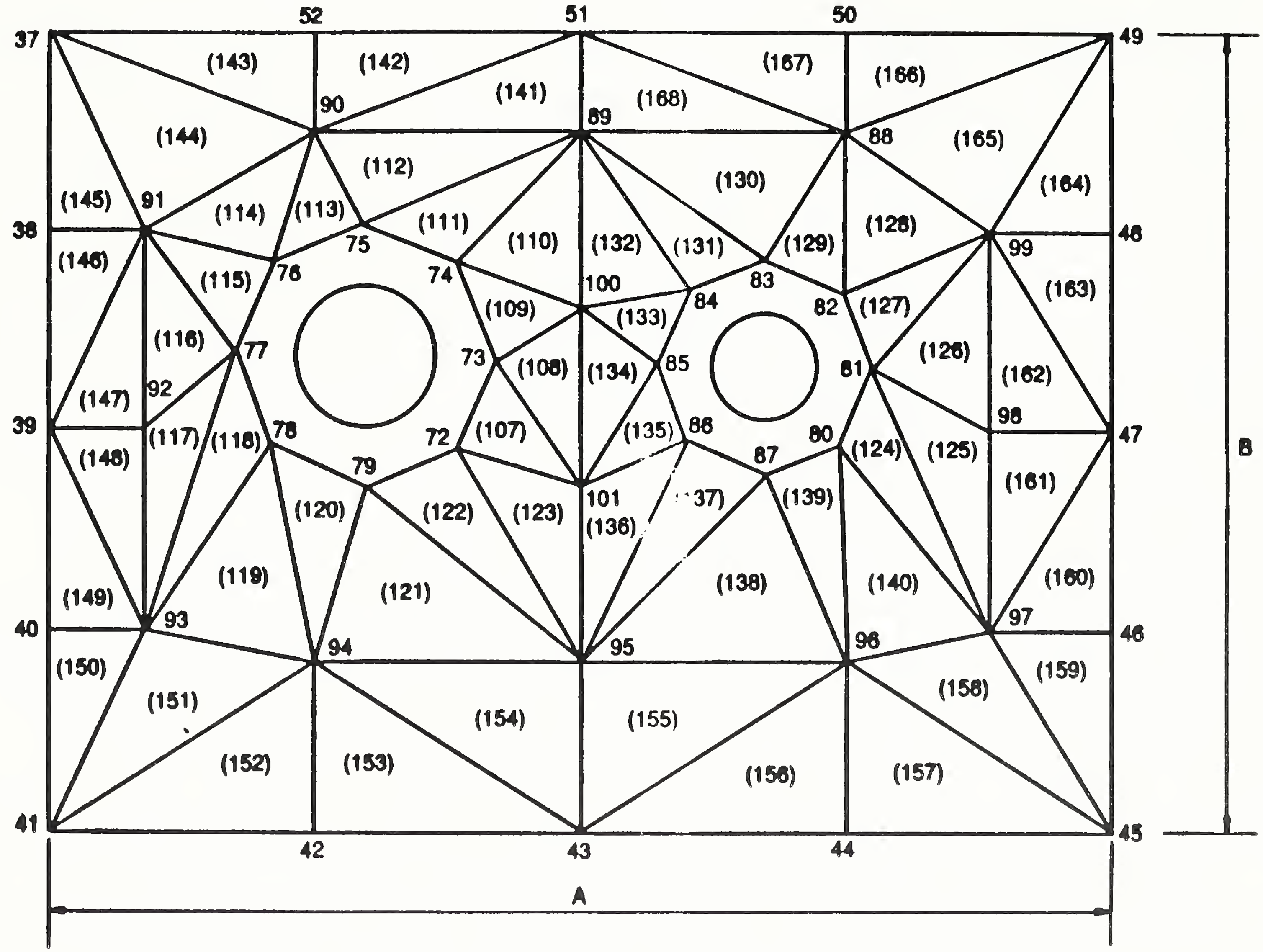


Figure 4.c Finite Element Design for Air Space Surrounding the Pipe Section Without Structural Supports

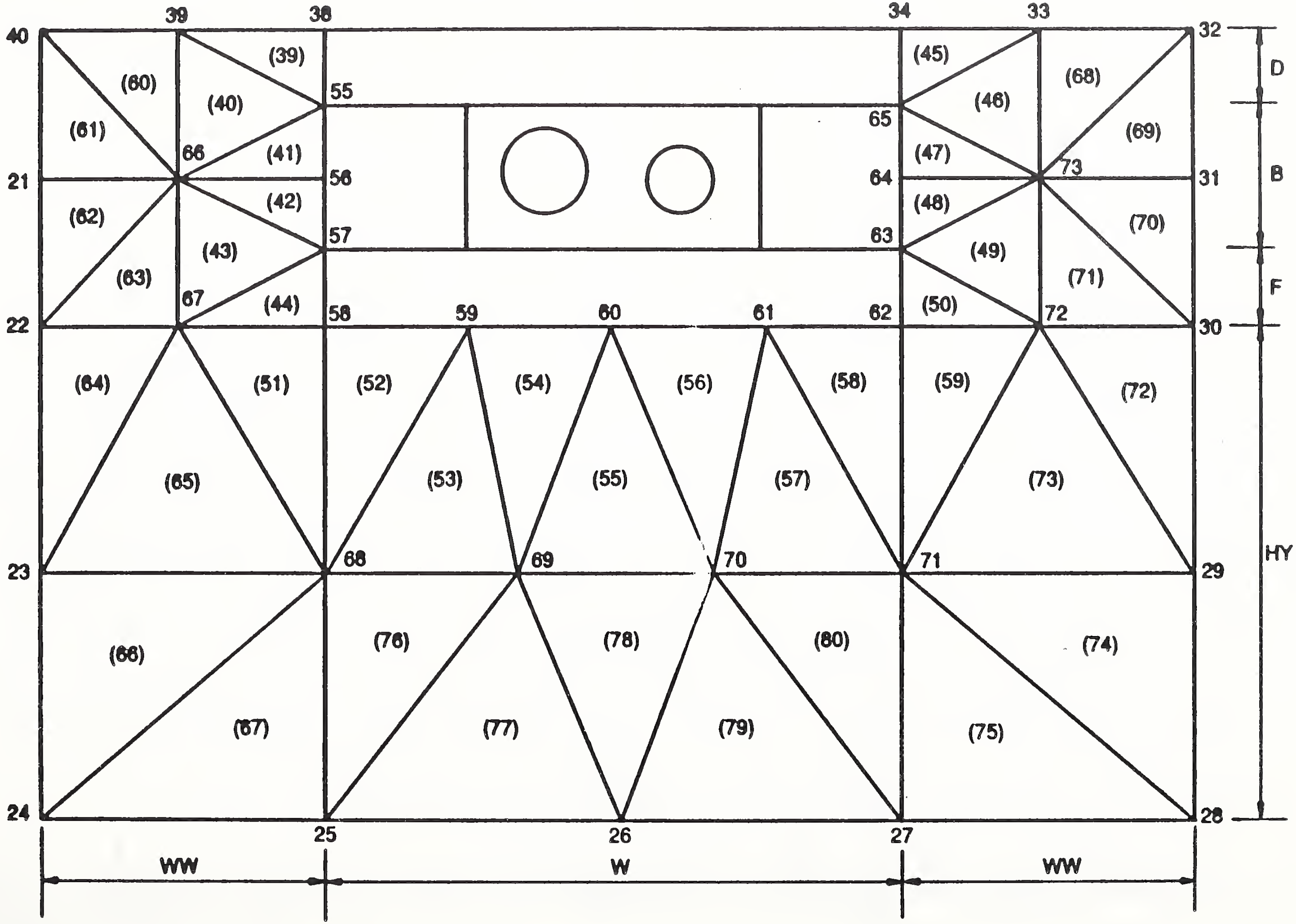


Figure 5.a Finite Element Design for Earth Region Surrounding the Concrete Trench for Vertical Piping Supports

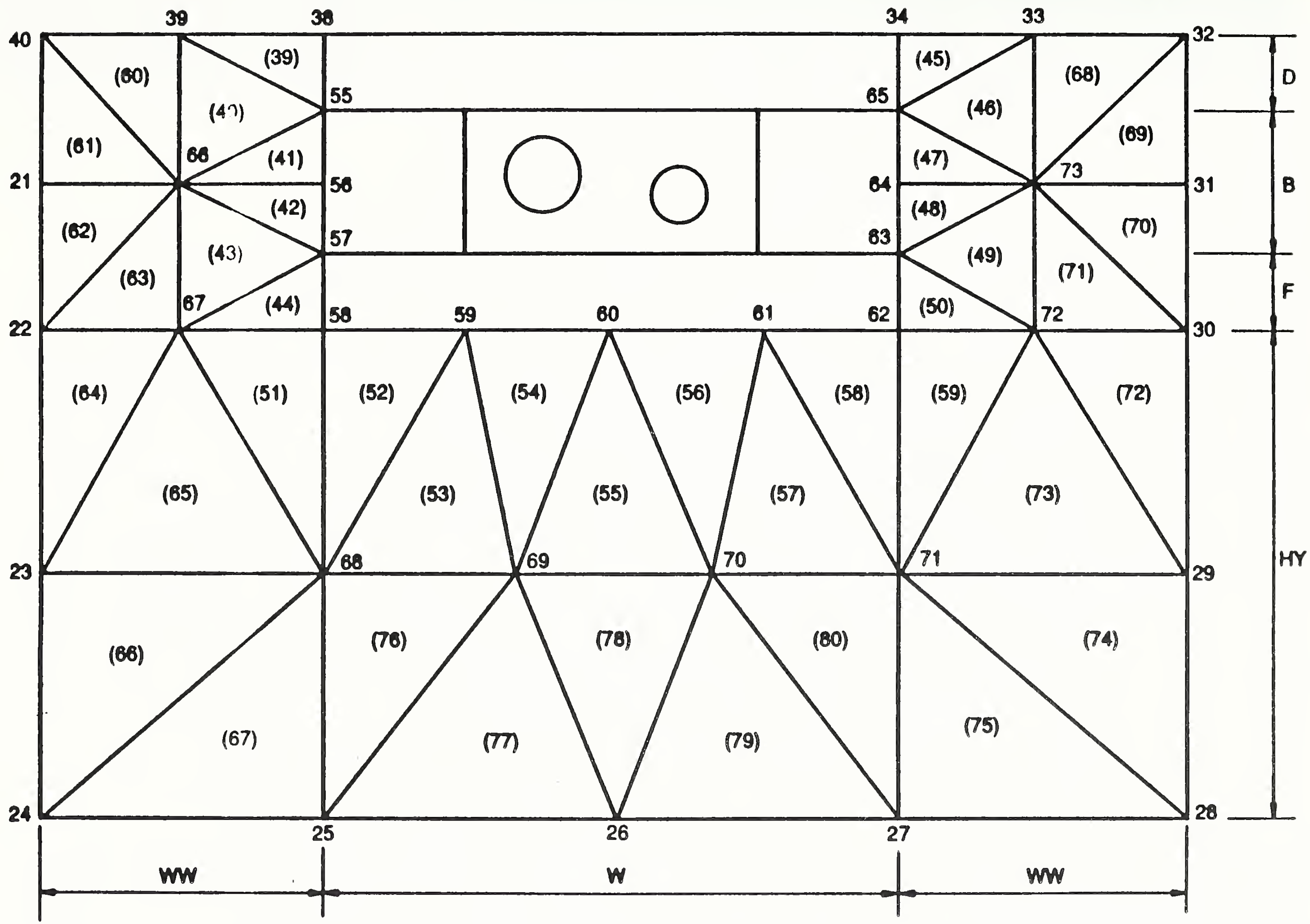


Figure 5.b Finite Element Design for Earth Region Surrounding the Concrete Trench for Horizontal Piping Supports

APPENDIX A. The Input Data Files and the Outputs from the Computer Programs

A.1 A Listing of DATAV1 Input File for Program UHDSV

```
STEAM DISTRIBUTION SYSTEM WITH VERTICAL PIPE SUPPORTS
132,226,31,81
1
1,1
9.70,6.0,0.75,0.6667
68.0,8.0
385.0,210.0
0.44,15.0,372.0,1
6.625,3.50
3.50,2.50
2.125,2.266
0.625,0.8333,56.0
10.0,20.0
4.99,4.865,10.0,7.96,0.34,0.29,0.56,0.435
0.19,36.0
6.0,0.50
3.0,2.67
56.0,0.0,0.025
```

A-2 A Listing of DATAV2 Input File for Program UHDSV

```
1,41,55,42,1
2,42,55,56,1
3,42,56,43,1
4,43,56,129,1
5,43,129,125,1
6,56,57,129,1
7,57,130,129,1
8,44,130,57,1
9,44,126,130,1
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13,49,132,64,1
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26,37,41,54,1
27,37,55,41,1
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31,44,59,45,1
32,59,60,45,1
33,45,60,46,1
34,46,60,47,1
35,60,61,47,1
36,47,61,48,1
37,48,61,63,1
38,61,62,63,1
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42,56,66,57,4
43,57,66,67,4
44,57,67,58,4
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46,33,65,73,4
47,65,64,73,4
48,64,63,73,4
49,63,72,73,4
50,63,62,72,4
51,58,67,68,4
52,59,58,68,4
53,59,68,69,4
54,60,59,69,4
55,60,69,70,4
56,61,60,70,4
57,61,70,71,4
58,62,61,71,4
59,62,71,72,4
60,39,40,66,4
61,40,21,66,4
62,21,22,66,4
63,22,67,66,4
64,22,23,67,4
65,23,68,67,4
66,23,24,68,4
67,24,25,68,4
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69,31,32,73,4
70,30,31,73,4
71,30,73,72,4
72,29,30,72,4
73,29,72,71,4
```

74,28,29,71,4
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77,25,26,69,4
78,26,70,69,4
79,26,27,70,4
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106,13,87,14,2
107,14,87,15,2
108,15,87,88,2
109,15,88,106,2
110,15,106,19,2
111,9,20,107,2
112,9,107,82,2
113,74,102,75,3
114,75,102,101,3
115,75,101,76,3
116,76,101,91,3
117,76,91,77,3
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124,80,94,95,3
125,80,95,104,3
126,95,108,104,3
127,96,105,109,3
128,96,74,105,3
129,74,96,102,3
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137,86,91,101,3
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139,87,101,102,3
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142,88,97,106,3
143,97,110,106,3
144,107,111,98,3
145,107,98,82,3
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160,103,97,102,3
161,103,116,97,3
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179,46,47,123,3
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185,8,81,105,5
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188,16,106,89,5
189,16,89,107,5
190,20,16,107,5
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202,97,116,110,5
203,116,117,110,5
204,110,117,111,5
205,111,117,118,5
206,111,118,98,5
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208,113,120,121,5
209,113,121,114,5
210,114,121,122,5
211,114,122,115,5
212,115,122,103,5
213,103,122,116,5
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215,122,123,117,5
216,117,123,118,5
217,118,123,124,5
218,124,119,118,5
219,112,125,129,5

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220,112,129,130,5
221,120,112,130,5
222,126,120,130,5
223,128,119,132,5
224,119,131,132,5
225,119,124,131,5
226,124,127,131,5
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45,3.0,0.0,0.0,45.0,45.0,45.0
19,3.0,0.0,0.0,45.0,45.0,45.0
22,3.0,0.0,0.0,45.0,45.0,45.0
25,3.0,0.0,0.0,45.0,45.0,45.0
28,3.0,0.0,0.0,45.0,45.0,45.0
39,3.0,0.0,0.0,45.0,45.0,45.0
60,3.0,0.0,0.0,45.0,45.0,45.0
```

A.3 A Listing of DATAH1 Input File for Program UHDSH

```
STEAM DISTRIBUTION SYSTEM WITH HORIZONTAL PIPE SUPPORTS
121,204,31,81
1
1,1
9.70,6.0,0.75,0.6667
68.0,8.0
385.0,210.0
0.44,15.0,372.0,1
6.625,3.50
3.50,2.50
2.125,2.266
0.625,0.8333,56.0
10.0,20.0
7.188,6.250,0.375,0.375
8.0,0.50
3.0,2.67
56.0,0.0,0.025
```

A.4 A Listing of DATAH2 Input File for Program UHDSH

```
1,41,55,42,1
2,42,55,118,1
3,55,56,118,1
4,42,118,114,1
5,56,119,118,1
6,56,57,119,1
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8,43,115,119,1
9,44,43,57,1
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69,31,32,73,4
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73,29,72,71,4
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104,13,85,86,2
105,13,86,87,2
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137,85,91,86,3
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141,87,105,88,3
142,88,105,98,3
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144,89,98,99,3
145,89,99,82,3
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165,46,99,98,3
166,46,47,99,3
167,47,48,99,3
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172,49,116,100,3
173,116,112,101,3
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177,117,50,103,3
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184,6,106,79,5
185,6,79,107,5
186,6,107,18,5
187,10,19,108,5
188,10,108,83,5
189,10,83,109,5
190,10,109,20,5
191,79,106,110,5
192,79,110,111,5
193,79,111,107,5
194,83,108,112,5
195,83,112,113,5
196,83,113,109,5
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200,115,111,119,5
201,117,113,121,5
202,113,120,121,5
203,113,112,120,5
204,112,116,120,5
8
68,3.0,0.0,0.0,45.0,45.0,45.0
45,3.0,0.0,0.0,45.0,45.0,45.0
19,3.0,0.0,0.0,45.0,45.0,45.0
22,3.0,0.0,0.0,45.0,45.0,45.0
25,3.0,0.0,0.0,45.0,45.0,45.0
28,3.0,0.0,0.0,45.0,45.0,45.0
39,3.0,0.0,0.0,45.0,45.0,45.0
60,3.0,0.0,0.0,45.0,45.0,45.0
```

A.5 A Listing of DATA1 Input File for Program UHDS

```
STEAM DISTRIBUTION SYSTEM WITH NO PIPE SUPPORTS
101,168,27,75
3,1
1,1
9.7,6.0,0.75,0.6667
68.0,8.0
385.0,210.0
0.44,15.0,1
6.625,3.50
3.50,2.50
2.125,2.266
0.625,0.8333,56.0
10.0,20.0
3.00,2.67
56.0,0.0,0.025
```

A.6 A Listing of DATA2 Input File for Program UHDS

```
1,37,53,38,1
2,38,53,54,1
3,38,54,39,1
4,39,54,40,1
5,40,54,55,1
6,40,55,41,1
7,41,55,57,1
8,57,55,56,1
9,63,49,48,1
10,63,48,62,1
11,62,48,47,1
12,62,47,46,1
13,62,46,61,1
14,61,46,45,1
15,61,45,59,1
16,61,59,60,1
17,30,31,63,1
18,31,49,63,1
19,49,31,50,1
20,31,32,50,1
21,50,32,51,1
22,51,32,52,1
23,32,33,52,1
24,52,33,37,1
25,37,33,53,1
26,33,34,53,1
27,42,41,57,1
28,42,57,58,1
29,43,42,58,1
30,44,43,58,1
31,44,58,59,1
32,45,44,59,1
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34,53,35,64,4
35,53,64,54,4
36,54,64,55,4
37,55,64,65,4
38,55,65,56,4
39,29,30,63,4
40,29,63,71,4
41,63,62,71,4
42,62,61,71,4
43,71,61,70,4
44,61,60,70,4
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46,56,66,57,4
47,57,66,67,4
48,58,57,67,4
49,58,67,68,4
50,59,58,68,4
51,59,68,69,4
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53,70,60,69,4
54,35,36,64,4
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56,64,17,18,4
57,64,18,65,4
58,65,18,19,4
59,65,19,66,4
60,66,19,20,4
61,66,20,21,4
62,28,29,71,4
63,28,71,27,4
64,27,71,26,4
65,71,70,26,4
66,26,70,25,4
67,70,69,25,4
68,25,69,24,4
69,69,23,24,4
70,67,66,21,4
71,67,21,22,4
72,68,67,22,4
73,68,22,23,4
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74,69,68,23,4
75,1,72,73,2
76,2,1,73,2
77,3,2,73,2
78,3,73,74,2
79,3,74,75,2
80,4,3,75,2
81,5,4,75,2
82,5,75,76,2
83,5,76,77,2
84,6,5,77,2
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86,7,77,78,2
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145,91,37,38,3
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26,3.0,0.0,0.0,45.0,45.0,45.0
33,3.0,0.0,0.0,45.0,45.0,45.0
54,3.0,0.0,0.0,45.0,45.0,45.0
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A.7 Output File OTFILEV from Program UHDSV

```
STEAM DISTRIBUTION SYSTEM WITH VERTICAL PIPE SUPPORTS
  TP1     TP2      KI      KG      D1      D2
385.00 210.00     .44   15.00    6.63    3.50
  THI1    THI2     DP1     DP2      S1      S2      TG
  3.50    2.50    2.13    2.27     .63     .83   56.00
   WW      HY    MONTH
 10.00   20.00       1
   SH1     SH2     SW1     SW2     ST1     ST2     FT1     FT2
 4.990   4.865  10.000   7.960    .340    .290    .560    .435
   BPT     BPW      PH      PW
  .190  36.000   6.000    .500
    W       H       D       F       A       B      WW      HY
  4.00    4.09     .75     .67    3.00    2.67   10.00   20.00
   XC1     YC1     XC2     YC2
 1.375   2.125   2.833   2.266
  DI1     DI2     S1      S2    THI1     KII     KIG     TP1     TP2
 6.63    3.50    .63     .83    3.50     .44   15.00    385.    210.
   Q1      Q2      QT      KP
 95.97   27.62  123.59    .512

 X(M),M=1,NN
  1.57    1.65    1.57    1.38    1.18    1.10    1.18    1.38    2.94    2.98
  2.94    2.83    2.73    2.69    2.73    2.83    1.36    1.39    2.82    2.85
-10.00  -10.00  -10.00  -10.00     .00    2.00    4.00   14.00   14.00   14.00
 14.00   14.00    9.00    4.00    3.50    2.00     .50     .00   -5.00  -10.00
   .50     .50     .50     .50    1.25    2.00    2.75    3.50    3.50    3.50
  3.50    2.75    2.00    1.25     .00     .00     .00     .00     .50    2.00
  3.50    4.00    4.00    4.00    4.00   -5.00   -5.00     .00    1.33    2.67
  4.00    9.00    9.00    1.78    1.94    1.78    1.38     .97     .81     .97
  1.38    3.08    3.19    3.08    2.83    2.58    2.48    2.58    2.83    2.75
  2.00    1.25     .65     .65     .96    1.79    2.50    3.16    2.09    1.42
  2.00    2.00    2.00    1.36    1.39    2.82    2.85    1.36    1.39    2.82
  2.85     .50     .96    1.39    1.79    2.50    2.82    3.16    3.50     .50
  1.25    2.00    2.75    3.50     .50     .50    3.50    3.50     .46     .46
  3.54    3.54
 Y(M),M=1,NN
  2.32    2.13    1.93    1.85    1.93    2.13    2.32    2.40    2.37    2.27
  2.16    2.12    2.16    2.27    2.37    2.41    2.40    2.40    2.41    2.41
  2.04    4.09   14.09   24.09   24.09   24.09   24.09   24.09   14.09    4.09
  2.04     .00     .00     .00     .00     .00     .00     .00     .00     .00
   .75    1.42    2.09    3.42    3.42    3.42    3.42    3.42    2.09    1.42
   .75     .75     .75     .75     .75    2.09    3.42    4.09    4.09    4.09
  4.09    4.09    3.42    2.09     .75    2.04    4.09   14.09   14.09   14.09
 14.09    4.09    2.04    2.53    2.13    1.72    1.56    1.72    2.13    2.53
  2.69    2.52    2.27    2.02    1.91    2.02    2.27    2.52    2.62    1.15
  1.15    1.15    1.42    2.09    2.77    2.77    2.78    2.78    3.34    3.34
   .55    1.11    2.82    2.69    2.69    2.62    2.62    2.77    2.77    2.78
  2.78    2.82    2.82    2.82    2.82    2.82    2.82    2.82    2.82    2.83
  2.83    2.83    2.83    2.83    2.57    3.07    3.08    2.58    2.57    3.07
  3.08    2.58
      QQ     ARRAY
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .42314E+03  .67500E+03  .37125E+03  .13500E+03  .20250E+03
 .13500E+03  .37125E+03  .67500E+03  .42314E+03  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .28607E+02
 .10180E+03  .10092E+03  .93333E+01  .93333E+01  .10092E+03  .10180E+03
 .28607E+02  .16514E+02  .16915E+02  .16915E+02  .16915E+02  .16915E+02
 .16915E+02  .16514E+02 -.42645E+04  .73931E+01  .76547E+01  .76547E+01
 .76547E+01  .76547E+01  .76547E+01  .73931E+01 -.22542E+04  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .28195E+04  .28195E+04  .15730E+04  .15730E+04  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
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KASP= 6.3123 (BTU-IN./H-FT**2-DEG F)

AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
KI1 = .440 KI2 = .440 BTU-IN/H-FT**2-DEG F

AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
T1= 202.03 T2= 38.09 DEG F

HEAT LOSSES FROM UNDERGROUND PIPES :
Q1= 1575.48 Q2= 209.67 QT= 1785.16 BTU/H-FT

QQ ARRAY

.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.42314E+03	.67500E+03	.37125E+03	.13500E+03	.20250E+03
.13500E+03	.37125E+03	.67500E+03	.42314E+03	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.28607E+02
.10180E+03	.10092E+03	.93333E+01	.93333E+01	.10092E+03	.10180E+03
.28607E+02	.17680E+02	.18391E+02	.17103E+02	.17932E+02	.16845E+02
.18166E+02	.17426E+02	-.42645E+04	.69691E+01	.72222E+01	.71330E+01
.72026E+01	.71927E+01	.73084E+01	.70724E+01	-.22542E+04	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.28204E+04	.28204E+04	.15729E+04	.15729E+04	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00

KASP= 6.0615 (BTU-IN./H-FT**2-DEG F)

AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
KI1 = .472 KI2 = .417 BTU-IN/H-FT**2-DEG F

AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
T1= 208.23 T2= 41.91 DEG F

HEAT LOSSES FROM UNDERGROUND PIPES :
Q1= 1687.24 Q2= 267.34 QT= 1954.58 BTU/H-FT

M	I	J	K	MAT.	C
1	41	55	42	1	.8083
2	42	55	56	1	.8083
3	42	56	43	1	.8083
4	43	56	129	1	.8083
5	43	129	125	1	.8083
6	56	57	129	1	.8083
7	57	130	129	1	.8083
8	44	130	57	1	.8083
9	44	126	130	1	.8083
10	51	50	65	1	.8083
11	50	64	65	1	.8083
12	50	49	64	1	.8083
13	49	132	64	1	.8083
14	49	128	132	1	.8083
15	64	132	63	1	.8083
16	63	132	131	1	.8083
17	48	63	131	1	.8083
18	48	131	127	1	.8083
19	34	35	65	1	.8083
20	35	51	65	1	.8083
21	35	52	51	1	.8083
22	35	36	52	1	.8083
23	36	53	52	1	.8083
24	36	54	53	1	.8083
25	36	37	54	1	.8083
26	37	41	54	1	.8083
27	37	55	41	1	.8083
28	37	38	55	1	.8083
29	58	59	57	1	.8083

30	57	59	44	1	.8083
31	44	59	45	1	.8083
32	59	60	45	1	.8083
33	45	60	46	1	.8083
34	46	60	47	1	.8083
35	60	61	47	1	.8083
36	47	61	48	1	.8083
37	48	61	63	1	.8083
38	61	62	63	1	.8083
39	38	39	55	4	1.2500
40	39	66	55	4	1.2500
41	55	66	56	4	1.2500
42	56	66	57	4	1.2209
43	57	66	67	4	1.2500
44	57	67	58	4	1.1980
45	33	34	65	4	1.2500
46	33	65	73	4	1.2500
47	65	64	73	4	1.2500
48	64	63	73	4	1.2500
49	63	72	73	4	1.2500
50	63	62	72	4	1.2491
51	58	67	68	4	1.2500
52	59	58	68	4	1.2132
53	59	68	69	4	1.2500
54	60	59	69	4	1.2045
55	60	69	70	4	1.2500
56	61	60	70	4	1.2194
57	61	70	71	4	1.2500
58	62	61	71	4	1.2458
59	62	71	72	4	1.2500
60	39	40	66	4	1.2500
61	40	21	66	4	1.2500
62	21	22	66	4	1.2500
63	22	67	66	4	1.2500
64	22	23	67	4	1.2500
65	23	68	67	4	1.2500
66	23	24	68	4	1.2500
67	24	25	68	4	1.2500
68	32	33	73	4	1.2500
69	31	32	73	4	1.2500
70	30	31	73	4	1.2500
71	30	73	72	4	1.2500
72	29	30	72	4	1.2500
73	29	72	71	4	1.2500
74	28	29	71	4	1.2500
75	27	28	71	4	1.2500
76	25	69	68	4	1.2500
77	25	26	69	4	1.2500
78	26	70	69	4	1.2500
79	26	27	70	4	1.2500
80	27	71	70	4	1.2500
81	1	74	75	2	.0384
82	1	75	2	2	.0407
83	2	75	3	2	.0407
84	3	75	76	2	.0373
85	3	76	77	2	.0364
86	3	77	4	2	.0401
87	4	77	5	2	.0401
88	5	77	78	2	.0361
89	5	78	79	2	.0366
90	5	79	6	2	.0404
91	6	79	7	2	.0404
92	7	79	80	2	.0377
93	7	80	104	2	.0393
94	7	104	17	2	.0415
95	1	18	105	2	.0415
96	1	105	74	2	.0396
97	9	82	83	2	.0343
98	9	83	10	2	.0348
99	10	83	11	2	.0348
100	11	83	84	2	.0342
101	11	84	85	2	.0341
102	11	85	12	2	.0347

103	12	85	13	2	.0347
104	13	85	86	2	.0342
105	13	86	87	2	.0345
106	13	87	14	2	.0351
107	14	87	15	2	.0351
108	15	87	88	2	.0349
109	15	88	106	2	.0350
110	15	106	19	2	.0353
111	9	20	107	2	.0353
112	9	107	82	2	.0347
113	74	102	75	3	.5051
114	75	102	101	3	.5051
115	75	101	76	3	.5051
116	76	101	91	3	.5051
117	76	91	77	3	.5051
118	77	91	92	3	.5051
119	77	92	78	3	.5051
120	78	92	93	3	.5051
121	78	93	79	3	.5051
122	79	93	94	3	.5051
123	79	94	80	3	.5051
124	80	94	95	3	.5051
125	80	95	104	3	.5051
126	95	108	104	3	.5051
127	96	105	109	3	.5051
128	96	74	105	3	.5051
129	74	96	102	3	.5051
130	82	99	83	3	.5051
131	83	99	100	3	.5051
132	84	83	100	3	.5051
133	84	100	90	3	.5051
134	85	84	90	3	.5051
135	85	90	91	3	.5051
136	86	85	91	3	.5051
137	86	91	101	3	.5051
138	86	101	87	3	.5051
139	87	101	102	3	.5051
140	87	102	88	3	.5051
141	88	102	97	3	.5051
142	88	97	106	3	.5051
143	97	110	106	3	.5051
144	107	111	98	3	.5051
145	107	98	82	3	.5051
146	82	98	99	3	.5051
147	53	92	91	3	.5051
148	53	54	92	3	.5051
149	54	41	92	3	.5051
150	92	41	93	3	.5051
151	41	42	93	3	.5051
152	42	43	93	3	.5051
153	93	43	94	3	.5051
154	43	125	94	3	.5051
155	94	125	95	3	.5051
156	125	112	95	3	.5051
157	112	113	95	3	.5051
158	96	115	103	3	.5051
159	96	103	102	3	.5051
160	103	97	102	3	.5051
161	103	116	97	3	.5051
162	98	118	119	3	.5051
163	98	119	128	3	.5051
164	98	128	99	3	.5051
165	99	128	49	3	.5051
166	99	49	100	3	.5051
167	49	50	100	3	.5051
168	50	51	100	3	.5051
169	51	90	100	3	.5051
170	51	52	90	3	.5051
171	52	53	90	3	.5051
172	53	91	90	3	.5051
173	120	126	121	3	.5051
174	126	45	121	3	.5051
175	44	45	126	3	.5051

176	45	46	121	3	.5051
177	46	122	121	3	.5051
178	46	123	122	3	.5051
179	46	47	123	3	.5051
180	47	48	127	3	.5051
181	47	127	123	3	.5051
182	127	124	123	3	.5051
183	8	17	104	5	31.0000
184	8	104	81	5	31.0000
185	8	81	105	5	31.0000
186	18	8	105	5	31.0000
187	16	19	106	5	31.0000
188	16	106	89	5	31.0000
189	16	89	107	5	31.0000
190	20	16	107	5	31.0000
191	81	104	108	5	31.0000
192	81	108	109	5	31.0000
193	81	109	105	5	31.0000
194	89	106	110	5	31.0000
195	89	110	111	5	31.0000
196	89	111	107	5	31.0000
197	95	113	108	5	31.0000
198	108	113	114	5	31.0000
199	108	114	109	5	31.0000
200	109	114	115	5	31.0000
201	109	115	96	5	31.0000
202	97	116	110	5	31.0000
203	116	117	110	5	31.0000
204	110	117	111	5	31.0000
205	111	117	118	5	31.0000
206	111	118	98	5	31.0000
207	112	120	113	5	31.0000
208	113	120	121	5	31.0000
209	113	121	114	5	31.0000
210	114	121	122	5	31.0000
211	114	122	115	5	31.0000
212	115	122	103	5	31.0000
213	103	122	116	5	31.0000
214	116	122	117	5	31.0000
215	122	123	117	5	31.0000
216	117	123	118	5	31.0000
217	118	123	124	5	31.0000
218	124	119	118	5	31.0000
219	112	125	129	5	31.0000
220	112	129	130	5	31.0000
221	120	112	130	5	31.0000
222	126	120	130	5	31.0000
223	128	119	132	5	31.0000
224	119	131	132	5	31.0000
225	119	124	131	5	31.0000
226	124	127	131	5	31.0000

QQ ARRAY

.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.42314E+03	.67500E+03	.37125E+03	.13500E+03	.20250E+03
.13500E+03	.37125E+03	.67500E+03	.42314E+03	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.28607E+02
.10180E+03	.10092E+03	.93333E+01	.93333E+01	.10092E+03	.10180E+03
.28607E+02	.17550E+02	.18322E+02	.17008E+02	.17884E+02	.16768E+02
.18130E+02	.17343E+02	-.42645E+04	.69546E+01	.72125E+01	.71207E+01
.71937E+01	.71749E+01	.72877E+01	.70436E+01	-.22542E+04	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.28203E+04	.28204E+04	.15729E+04	.15729E+04	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00

```
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
KASP=    6.0833  (BTU-IN./H-FT**2-DEG F)

AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
 KI1 =       .470   KI2 =       .417   BTU-IN/H-FT**2-DEG F

AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
 T1=     207.76   T2=      41.64  DEG F

HEAT LOSSES FROM UNDERGROUND PIPES :
 Q1=   1676.78   Q2=    261.98   QT=   1938.76  BTU/H-FT
    QQ    ARRAY
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .42314E+03  .67500E+03  .37125E+03  .13500E+03  .20250E+03
.13500E+03  .37125E+03  .67500E+03  .42314E+03  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .28607E+02
.10180E+03  .10092E+03  .93333E+01  .93333E+01  .10092E+03  .10180E+03
.28607E+02  .17561E+02  .18328E+02  .17014E+02  .17887E+02  .16772E+02
.18133E+02  .17350E+02 -.42645E+04  .69557E+01  .72131E+01  .71214E+01
.71942E+01  .71762E+01  .72893E+01  .70460E+01 -.22542E+04  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .28203E+04  .28204E+04  .15729E+04  .15729E+04  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
KASP=    6.0814  (BTU-IN./H-FT**2-DEG F)

AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
 KI1 =       .470   KI2 =       .417   BTU-IN/H-FT**2-DEG F

AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
 T1=     207.81   T2=      41.66  DEG F

HEAT LOSSES FROM UNDERGROUND PIPES :
 Q1=   1677.70   Q2=    262.46   QT=   1940.16  BTU/H-FT
TEMPERATURE ARRAY : T(I), I=1,NN
.38500E+03  .38500E+03  .38500E+03  .38500E+03  .38500E+03  .38500E+03
.38500E+03  .38500E+03  .21000E+03  .21000E+03  .21000E+03  .21000E+03
.21000E+03  .21000E+03  .21000E+03  .21000E+03  .38500E+03  .38500E+03
.21000E+03  .21000E+03  .56000E+02  .56000E+02  .56000E+02  .56000E+02
.56000E+02  .56000E+02  .56000E+02  .56000E+02  .56000E+02  .56000E+02
.56000E+02  .46936E+02  .46643E+02  .57435E+02  .54952E+02  .56594E+02
.55600E+02  .60427E+02  .46870E+02  .46861E+02  .83216E+02  .11240E+03
.15017E+03  .15984E+03  .16900E+03  .16972E+03  .15106E+03  .13099E+03
.12350E+03  .10067E+03  .80880E+02  .86471E+02  .89131E+02  .85839E+02
.82151E+02  .12103E+03  .13269E+03  .12455E+03  .12794E+03  .12975E+03
.11825E+03  .11327E+03  .11413E+03  .10313E+03  .74906E+02  .65191E+02
.76605E+02  .71212E+02  .71691E+02  .71450E+02  .70548E+02  .72504E+02
.62212E+02  .22509E+03  .19383E+03  .16142E+03  .13889E+03  .14232E+03
.16911E+03  .20971E+03  .26424E+03  .16740E+03  .16021E+03  .15377E+03
.15241E+03  .16563E+03  .18367E+03  .19527E+03  .19541E+03  .11450E+03
.12047E+03  .11098E+03  .11628E+03  .15952E+03  .21944E+03  .24024E+03
.20852E+03  .16552E+03  .19679E+03  .20629E+03  .96419E+02  .13009E+03
.24246E+03  .26656E+03  .26657E+03  .19573E+03  .19572E+03  .23635E+03
.23704E+03  .18700E+03  .18625E+03  .19638E+03  .21922E+03  .23599E+03
.24029E+03  .20871E+03  .18720E+03  .16597E+03  .14531E+03  .19643E+03
.23288E+03  .24254E+03  .19185E+03  .14516E+03  .19513E+03  .19567E+03
.14258E+03  .14837E+03  .19517E+03  .19585E+03  .14250E+03  .14781E+03
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A.8 Output File OTFILEH from Program UHDSH

```
STEAM DISTRIBUTION SYSTEM WITH HORIZONTAL PIPE SUPPORTS
  TP1     TP2      KI      KG      D1      D2
385.00 210.00     .44   15.00    6.63    3.50
  THI1    THI2     DP1     DP2      S1      S2      TG
  3.50    2.50    2.13    2.27     .63     .83   56.00
    WW      HY   MONTH
 10.00   20.00       1
   SW1     SW2     ST1     ST2      PH      PW
 7.188   6.250    .375    .375   8.000    .500
     W       H       D       F       A       B      WW      HY
  4.00    4.09     .75     .67    3.00    2.67   10.00   20.00
   XC1     YC1     XC2     YC2
 1.375   2.125   2.833   2.266
   DI1     DI2     S1      S2     THI1     KII     KIG     TP1     TP2
  6.63    3.50    .63     .83     3.50     .44   15.00    385.    210.
    Q1      Q2      QT      KP
 95.97   27.62  123.59    .512

 X(M),M=1,NN
  1.57    1.65    1.57    1.38    1.18    1.10    1.18    1.38    2.94    2.98
  2.94    2.83    2.73    2.69    2.73    2.83    1.11    1.11    2.97    2.97
-10.00  -10.00  -10.00  -10.00     .00    2.00    4.00   14.00   14.00   14.00
 14.00   14.00    9.00    4.00    3.50    2.00     .50     .00   -5.00  -16.00
   .50     .50     .50     .50    1.25    2.00    2.75    3.50    3.50    3.50
  3.50    2.75    2.00    1.25     .00     .00     .00     .00     .50    2.00
  3.50    4.00    4.00    4.00    4.00   -5.00   -5.00     .00    1.33    2.67
  4.00    9.00    9.00    1.78    1.94    1.78    1.38     .97     .81     .97
  1.38    3.08    3.19    3.08    2.83    2.58    2.48    2.58    2.83    2.75
  2.00    1.25     .65     .65     .65     .65    1.25    2.00    2.75    3.34
  3.34    3.34    3.34    2.00    2.00     .81     .81    3.18    3.18     .50
   .50    3.50    3.50     .50     .50    3.50    3.50     .46     .46    3.54
  3.54
 Y(M),M=1,NN
  2.32    2.13    1.93    1.85    1.93    2.13    2.32    2.40    2.37    2.27
  2.16    2.12    2.16    2.27    2.37    2.41    2.11    2.14    2.28    2.25
  2.04    4.09   14.09   24.09   24.09   24.09   24.09   24.09   14.09    4.09
  2.04     .00     .00     .00     .00     .00     .00     .00     .00     .00
   .75    1.27    2.94    3.42    3.42    3.42    3.42    3.42    3.01    1.34
   .75     .75     .75     .75     .75    2.09    3.42    4.09    4.09    4.09
  4.09    4.09    3.42    2.09     .75    2.04    4.09   14.09   14.09   14.09
 14.09    4.09    2.04    2.53    2.13    1.72    1.56    1.72    2.13    2.53
  2.69    2.52    2.27    2.02    1.91    2.02    2.27    2.52    2.62    1.15
  1.15    1.15    1.27    1.79    2.46    2.94    3.06    3.06    3.06    3.01
  2.60    1.93    1.34    1.79    2.42    2.11    2.14    2.28    2.25    2.11
  2.14    2.28    2.25    1.79    2.46    2.60    1.93    1.79    2.46    2.60
  1.93
     QQ      ARRAY
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .42314E+03  .67500E+03  .37125E+03  .13500E+03  .20250E+03
.13500E+03  .37125E+03  .67500E+03  .42314E+03  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .28607E+02
.10180E+03  .10092E+03  .93333E+01  .93333E+01  .10092E+03  .10180E+03
.28607E+02  .16915E+02  .16915E+02  .16915E+02  .16915E+02  .16472E+02
-.41946E+04 .16472E+02  .16915E+02  .73164E+01 -.21245E+04  .73164E+01
.76547E+01  .76547E+01  .76547E+01  .76547E+01  .76547E+01  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .28544E+04  .28544E+04  .16378E+04
.16378E+04  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00
 KASP=     6.1325   (BTU-IN./H-FT**2-DEG F)

 AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
  KI1 =        .440    KI2 =        .440    BTU-IN/H-FT**2-DEG F
```

AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
T1= 207.22 T2= 59.55 DEG F

HEAT LOSSES FROM UNDERGROUND PIPES :
Q1= 1338.11 Q2= 661.64 QT= 1999.76 BTU/H-FT

QQ ARRAY

.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.42314E+03	.67500E+03	.37125E+03	.13500E+03	.20250E+03
.13500E+03	.37125E+03	.67500E+03	.42314E+03	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.28607E+02
.10180E+03	.10092E+03	.93333E+01	.93333E+01	.10092E+03	.10180E+03
.28607E+02	.17151E+02	.18069E+02	.16928E+02	.18074E+02	.17316E+02
-.41946E+04	.17491E+02	.18244E+02	.68254E+01	-.21245E+04	.68059E+01
.71589E+01	.70944E+01	.71967E+01	.71130E+01	.71797E+01	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.28554E+04	.28554E+04	.16376E+04
.16376E+04	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
.00000E+00					

KASP= 5.9227 (BTU-IN./H-FT**2-DEG F)

AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
KI1 = .472 KI2 = .413 BTU-IN/H-FT**2-DEG F

AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
T1= 213.65 T2= 63.27 DEG F

HEAT LOSSES FROM UNDERGROUND PIPES :
Q1= 1410.34 Q2= 690.72 QT= 2101.06 BTU/H-FT

M	I	J	K	MAT.	C
1	41	55	42	1	.8083
2	42	55	118	1	.8083
3	55	56	118	1	.8083
4	42	118	114	1	.8083
5	56	119	118	1	.8083
6	56	57	119	1	.8083
7	57	43	119	1	.8083
8	43	115	119	1	.8083
9	44	43	57	1	.8083
10	51	50	65	1	.8083
11	50	121	65	1	.8083
12	65	121	64	1	.8083
13	50	117	121	1	.8083
14	64	121	120	1	.8083
15	63	64	120	1	.8083
16	49	63	120	1	.8083
17	49	120	116	1	.8083
18	48	63	49	1	.8083
19	34	35	65	1	.8083
20	35	51	65	1	.8083
21	35	52	51	1	.8083
22	35	36	52	1	.8083
23	36	53	52	1	.8083
24	36	54	53	1	.8083
25	36	37	54	1	.8083
26	37	41	54	1	.8083
27	37	55	41	1	.8083
28	37	38	55	1	.8083
29	58	59	57	1	.8083
30	57	59	44	1	.8083
31	44	59	45	1	.8083
32	59	60	45	1	.8083
33	45	60	46	1	.8083
34	46	60	47	1	.8083
35	60	61	47	1	.8083

36	47	61	48	1	.8083
37	48	61	63	1	.8083
38	61	62	63	1	.8083
39	38	39	55	4	1.2500
40	39	66	55	4	1.2500
41	55	66	56	4	1.2384
42	56	66	57	4	1.1903
43	57	66	67	4	1.2500
44	57	67	58	4	1.2188
45	33	34	65	4	1.2500
46	33	65	73	4	1.2500
47	65	64	73	4	1.2500
48	64	63	73	4	1.2500
49	63	72	73	4	1.2500
50	63	62	72	4	1.2500
51	58	67	68	4	1.2500
52	59	58	68	4	1.2457
53	59	68	69	4	1.2500
54	60	59	69	4	1.2482
55	60	69	70	4	1.2500
56	61	60	70	4	1.2500
57	61	70	71	4	1.2500
58	62	61	71	4	1.2500
59	62	71	72	4	1.2500
60	39	40	66	4	1.2500
61	40	21	66	4	1.2500
62	21	22	66	4	1.2500
63	22	67	66	4	1.2500
64	22	23	67	4	1.2500
65	23	68	67	4	1.2500
66	23	24	68	4	1.2500
67	24	25	68	4	1.2500
68	32	33	73	4	1.2500
69	31	32	73	4	1.2500
70	30	31	73	4	1.2500
71	30	73	72	4	1.2500
72	29	30	72	4	1.2500
73	29	72	71	4	1.2500
74	28	29	71	4	1.2500
75	27	28	71	4	1.2500
76	25	69	68	4	1.2500
77	25	26	69	4	1.2500
78	26	70	69	4	1.2500
79	26	27	70	4	1.2500
80	27	71	70	4	1.2500
81	1	74	75	2	.0368
82	1	75	2	2	.0403
83	2	75	3	2	.0403
84	3	75	76	2	.0365
85	3	76	77	2	.0364
86	3	77	4	2	.0403
87	4	77	5	2	.0403
88	5	77	78	2	.0372
89	5	78	106	2	.0396
90	5	106	17	2	.0419
91	7	18	107	2	.0419
92	7	107	80	2	.0398
93	7	80	81	2	.0378
94	8	7	81	2	.0405
95	1	8	81	2	.0405
96	1	81	74	2	.0371
97	9	82	108	2	.0344
98	9	108	19	2	.0350
99	11	20	109	2	.0350
100	11	109	84	2	.0343
101	11	84	85	2	.0338
102	11	85	12	2	.0345
103	12	85	13	2	.0345
104	13	85	86	2	.0338
105	13	86	87	2	.0339
106	13	87	14	2	.0347
107	14	87	15	2	.0347
108	15	87	88	2	.0340

109	15	88	89	2	.0340
110	16	15	89	2	.0346
111	9	16	89	2	.0346
112	9	89	82	2	.0340
113	74	105	75	3	.4936
114	75	105	104	3	.4936
115	75	104	76	3	.4936
116	76	104	91	3	.4936
117	76	91	77	3	.4936
118	77	91	92	3	.4936
119	77	92	78	3	.4936
120	78	92	94	3	.4936
121	78	94	106	3	.4936
122	94	110	106	3	.4936
123	95	107	111	3	.4936
124	80	107	95	3	.4936
125	80	95	97	3	.4936
126	81	80	97	3	.4936
127	81	97	98	3	.4936
128	81	98	74	3	.4936
129	74	98	105	3	.4936
130	82	101	108	3	.4936
131	101	112	108	3	.4936
132	102	109	113	3	.4936
133	84	109	102	3	.4936
134	84	102	90	3	.4936
135	85	84	90	3	.4936
136	85	90	91	3	.4936
137	85	91	86	3	.4936
138	86	91	104	3	.4936
139	86	104	87	3	.4936
140	87	104	105	3	.4936
141	87	105	88	3	.4936
142	88	105	98	3	.4936
143	89	88	98	3	.4936
144	89	98	99	3	.4936
145	89	99	82	3	.4936
146	82	99	101	3	.4936
147	53	92	91	3	.4936
148	53	54	92	3	.4936
149	54	41	92	3	.4936
150	92	41	93	3	.4936
151	41	42	93	3	.4936
152	42	114	93	3	.4936
153	93	114	94	3	.4936
154	92	93	94	3	.4936
155	94	114	110	3	.4936
156	111	115	95	3	.4936
157	115	43	96	3	.4936
158	95	115	96	3	.4936
159	95	96	97	3	.4936
160	43	44	96	3	.4936
161	44	97	96	3	.4936
162	44	45	97	3	.4936
163	45	46	97	3	.4936
164	46	98	97	3	.4936
165	46	99	98	3	.4936
166	46	47	99	3	.4936
167	47	48	99	3	.4936
168	48	100	99	3	.4936
169	48	49	100	3	.4936
170	99	100	101	3	.4936
171	100	116	101	3	.4936
172	49	116	100	3	.4936
173	116	112	101	3	.4936
174	113	117	102	3	.4936
175	90	102	103	3	.4936
176	117	103	102	3	.4936
177	117	50	103	3	.4936
178	50	51	103	3	.4936
179	51	90	103	3	.4936
180	51	52	90	3	.4936
181	52	53	90	3	.4936

```
  182    53    91    90     3     .4936
  183     6    17   106     5   31.0000
  184     6   106    79     5   31.0000
  185     6    79   107     5   31.0000
  186     6   107    18     5   31.0000
  187    10    19   108     5   31.0000
  188    10   108    83     5   31.0000
  189    10    83   109     5   31.0000
  190    10   109    20     5   31.0000
  191    79   106   110     5   31.0000
  192    79   110   111     5   31.0000
  193    79   111   107     5   31.0000
  194    83   108   112     5   31.0000
  195    83   112   113     5   31.0000
  196    83   113   109     5   31.0000
  197   110   114   118     5   31.0000
  198   110   118   119     5   31.0000
  199   111   110   119     5   31.0000
  200   115   111   119     5   31.0000
  201   117   113   121     5   31.0000
  202   113   120   121     5   31.0000
  203   113   112   120     5   31.0000
  204   112   116   120     5   31.0000
    QQ    ARRAY
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .42314E+03  .67500E+03  .37125E+03  .13500E+03  .20250E+03
 .13500E+03  .37125E+03  .67500E+03  .42314E+03  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .28607E+02
 .10180E+03  .10092E+03  .93333E+01  .93333E+01  .10092E+03  .10180E+03
 .28607E+02  .17032E+02  .17995E+02  .16808E+02  .18023E+02  .17246E+02
-.41946E+04  .17425E+02  .18196E+02  .68176E+01 -.21245E+04  .67951E+01
 .71471E+01  .70704E+01  .71773E+01  .70930E+01  .71714E+01  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .28553E+04  .28554E+04  .16376E+04
 .16376E+04  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00
 KASP=     5.9381   (BTU-IN./H-FT**2-DEG F)

 AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
  KI1 =        .470   KI2 =        .412   BTU-IN/H-FT**2-DEG F

 AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
  T1=      213.29    T2=       63.13   DEG F

 HEAT LOSSES FROM UNDERGROUND PIPES :
  Q1=    1403.41    Q2=     688.19    QT=    2091.60   BTU/H-FT
 TEMPERATURE ARRAY : T(I), I=1,NN
 .38500E+03  .38500E+03  .38500E+03  .38500E+03  .38500E+03  .38500E+03
 .38500E+03  .38500E+03  .21000E+03  .21000E+03  .21000E+03  .21000E+03
 .21000E+03  .21000E+03  .21000E+03  .21000E+03  .38500E+03  .38500E+03
 .21000E+03  .21000E+03  .56000E+02  .56000E+02  .56000E+02  .56000E+02
 .56000E+02  .56000E+02  .56000E+02  .56000E+02  .56000E+02  .56000E+02
 .56000E+02  .47062E+02  .46263E+02  .57910E+02  .54388E+02  .55658E+02
 .61083E+02  .67192E+02  .45783E+02  .47220E+02  .10316E+03  .15558E+03
 .17585E+03  .14004E+03  .13695E+03  .12960E+03  .12307E+03  .11642E+03
 .12920E+03  .10959E+03  .79539E+02  .81407E+02  .86361E+02  .94882E+02
 .97342E+02  .14502E+03  .12909E+03  .11631E+03  .11703E+03  .11430E+03
 .10675E+03  .10361E+03  .10692E+03  .10618E+03  .75885E+02  .65172E+02
 .74756E+02  .69001E+02  .69308E+02  .69029E+02  .68235E+02  .69686E+02
 .60924E+02  .16572E+03  .15538E+03  .14752E+03  .15314E+03  .19620E+03
 .29443E+03  .20896E+03  .17504E+03  .15246E+03  .17981E+03  .14658E+03
 .13832E+03  .14390E+03  .15092E+03  .14958E+03  .14631E+03  .10286E+03
 .11133E+03  .12721E+03  .15364E+03  .21481E+03  .22142E+03  .17582E+03
 .15797E+03  .14287E+03  .13433E+03  .13120E+03  .14687E+03  .14184E+03
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.11039E+03	.14418E+03	.15898E+03	.29621E+03	.29621E+03	.18062E+03
.18062E+03	.21711E+03	.21726E+03	.14326E+03	.14311E+03	.21427E+03
.21803E+03	.14445E+03	.14096E+03	.21427E+03	.21804E+03	.14447E+03
.14094E+03					

A. 9 Output File OUTFILE from Program UHDS

```
STEAM DISTRIBUTION SYSTEM WITH NO PIPE SUPPORTS
  TP1     TP2      KI      KG      D1      D2
385.00  210.00     .44   15.00    6.63    3.50
 THI1    THI2     DP1     DP2      S1      S2      TG
 3.50    2.50    2.13    2.27     .63     .83   56.00
   WW      HY   MONTH
10.00   20.00       1
    W       H       D       F       A       B      WW      HY
 4.00    4.09     .75     .67    3.00    2.67   10.00   20.00
  XC1     YC1     XC2     YC2
1.375   2.125   2.833   2.266
  DI1     DI2      S1      S2    THI1     KII     KIG     TP1     TP2
 6.63    3.50     .63     .83    3.50     .44   15.00    385.    210.
   Q1      Q2      QT      KP
95.97   27.62  123.59    .512

 X(M),M=1,NN
  1.57    1.65    1.57    1.38    1.18    1.10    1.18    1.38    2.94    2.98
  2.94    2.83    2.73    2.69    2.73    2.83  -10.00  -10.00  -10.00  -10.00
   .00    2.00    4.00   14.00   14.00   14.00   14.00   14.00    9.00    4.00
  3.50    2.00     .50     .00   -5.00  -10.00     .50     .50     .50     .50
   .50    1.25    2.00    2.75    3.50    3.50    3.50    3.50    3.50    2.75
  2.00    1.25     .00     .00     .00     .00     .50    2.00    3.50    4.00
  4.00    4.00    4.00   -5.00   -5.00     .00    1.33    2.67    4.00    9.00
  9.00    1.78    1.94    1.78    1.38     .97     .81     .97    1.38    3.08
  3.19    3.08    2.83    2.58    2.48    2.58    2.83    2.75    2.00    1.25
   .65     .65     .65    1.25    2.00    2.75    3.34    3.34    3.34    2.00
  2.00
 Y(M),M=1,NN
  2.32    2.13    1.93    1.85    1.93    2.13    2.32    2.40    2.37    2.27
  2.16    2.12    2.16    2.27    2.37    2.41    2.04    4.09   14.09   24.09
 24.09   24.09   24.09   24.09   14.09    4.09    2.04     .00     .00     .00
   .00     .00     .00     .00     .00     .00     .75    1.42    2.09    2.75
  3.42    3.42    3.42    3.42    3.42    2.75    2.09    1.42     .75     .75
   .75     .75     .75    2.09    3.42    4.09    4.09    4.09    4.09    4.09
  3.42    2.09     .75    2.04    4.09   14.09   14.09   14.09   14.09    4.09
  2.04    2.53    2.13    1.72    1.56    1.72    2.13    2.53    2.69    2.52
  2.27    2.02    1.91    2.02    2.27    2.52    2.62    1.15    1.15    1.15
  1.42    2.09    2.75    3.06    3.06    3.06    2.75    2.09    1.42    1.79
  2.42
     QQ     ARRAY
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .42314E+03  .67500E+03  .37125E+03
 .13500E+03  .20250E+03  .13500E+03  .37125E+03  .67500E+03  .42314E+03
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .28607E+02  .10180E+03  .10092E+03
 .93333E+01  .93333E+01  .10092E+03  .10180E+03  .28607E+02  .16915E+02
 .16915E+02  .16915E+02  .16915E+02  .16915E+02  .16915E+02  .16915E+02
 .16915E+02  .76547E+01  .76547E+01  .76547E+01  .76547E+01  .76547E+01
 .76547E+01  .76547E+01  .76547E+01  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 KASP=     5.5892  (BTU-IN./H-FT**2-DEG F)

 AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
  KI1 =        .440    KI2 =        .440    BTU-IN/H-FT**2-DEG F

 AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
  T1=      273.23    T2=      112.73   DEG F

 HEAT LOSSES FROM UNDERGROUND PIPES :
  Q1=      87.30    Q2=      29.27    QT=      116.57   BTU/H-FT
     QQ     ARRAY
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
 .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
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.00000E+00  .00000E+00  .00000E+00  .42314E+03  .67500E+03  .37125E+03
.13500E+03  .20250E+03  .13500E+03  .37125E+03  .67500E+03  .42314E+03
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .28607E+02  .10180E+03  .10092E+03
.93333E+01  .93333E+01  .10092E+03  .10180E+03  .28607E+02  .16369E+02
.17697E+02  .16286E+02  .17552E+02  .16093E+02  .17475E+02  .16142E+02
.17620E+02  .67822E+01  .69504E+01  .67748E+01  .69880E+01  .68751E+01
.70489E+01  .68759E+01  .69927E+01  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
KASP=    5.2374  (BTU-IN./H-FT**2-DEG F)

AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
 KI1 =       .449   KI2 =       .401   BTU-IN/H-FT**2-DEG F

AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
 T1=     284.30   T2=     121.22  DEG F

HEAT LOSSES FROM UNDERGROUND PIPES :
 Q1=     92.71   Q2=     28.66   QT=     121.37  BTU/H-FT
    QQ    ARRAY
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .42314E+03  .67500E+03  .37125E+03
.13500E+03  .20250E+03  .13500E+03  .37125E+03  .67500E+03  .42314E+03
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .28607E+02  .10180E+03  .10092E+03
.93333E+01  .93333E+01  .10092E+03  .10180E+03  .28607E+02  .16164E+02
.17552E+02  .16104E+02  .17453E+02  .16001E+02  .17413E+02  .16044E+02
.17514E+02  .67453E+01  .69292E+01  .67360E+01  .69556E+01  .68124E+01
.70043E+01  .68173E+01  .69630E+01  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
KASP=    5.2918  (BTU-IN./H-FT**2-DEG F)

AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
 KI1 =       .446   KI2 =       .399   BTU-IN/H-FT**2-DEG F

AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
 T1=     282.87   T2=     120.33  DEG F

HEAT LOSSES FROM UNDERGROUND PIPES :
 Q1=     91.64   Q2=     28.31   QT=     119.95  BTU/H-FT
    QQ    ARRAY
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .42314E+03  .67500E+03  .37125E+03
.13500E+03  .20250E+03  .13500E+03  .37125E+03  .67500E+03  .42314E+03
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .28607E+02  .10180E+03  .10092E+03
.93333E+01  .93333E+01  .10092E+03  .10180E+03  .28607E+02  .16191E+02
.17570E+02  .16123E+02  .17466E+02  .16013E+02  .17422E+02  .16056E+02
.17528E+02  .67486E+01  .69310E+01  .67396E+01  .69590E+01  .68195E+01
.70095E+01  .68238E+01  .69660E+01  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
.00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
KASP=    5.2828  (BTU-IN./H-FT**2-DEG F)

AVERAGE VALUES OF PIPE INSULATION THERMAL CONDUCTIVITY :
 KI1 =       .447   KI2 =       .399   BTU-IN/H-FT**2-DEG F
```

```
AVERAGE TEMPERATURE DROPS ACROSS INSULATION :
 T1=      283.11    T2=      120.48   DEG F

HEAT LOSSES FROM UNDERGROUND PIPES :
 Q1=      91.80    Q2=      28.36    QT=      120.16   BTU/H-FT
TEMPERATURE ARRAY : T(I), I=1,NN
.38500E+03  .38500E+03  .38500E+03  .38500E+03  .38500E+03  .38500E+03
.38500E+03  .38500E+03  .21000E+03  .21000E+03  .21000E+03  .21000E+03
.21000E+03  .21000E+03  .21000E+03  .21000E+03  .56000E+02  .56000E+02
.56000E+02  .56000E+02  .56000E+02  .56000E+02  .56000E+02  .56000E+02
.56000E+02  .56000E+02  .56000E+02  .47275E+02  .45617E+02  .48307E+02
.47630E+02  .49644E+02  .48635E+02  .49280E+02  .45568E+02  .47292E+02
.57725E+02  .67583E+02  .75313E+02  .73865E+02  .69245E+02  .75140E+02
.75948E+02  .72011E+02  .66273E+02  .68246E+02  .67428E+02  .61534E+02
.54703E+02  .58507E+02  .62199E+02  .61768E+02  .55278E+02  .63867E+02
.65305E+02  .64686E+02  .65487E+02  .66506E+02  .64258E+02  .63227E+02
.62912E+02  .60231E+02  .53052E+02  .52152E+02  .56327E+02  .57734E+02
.57817E+02  .57784E+02  .57646E+02  .55764E+02  .51702E+02  .11236E+03
.11017E+03  .10549E+03  .98023E+02  .93165E+02  .92618E+02  .97870E+02
.10540E+03  .83012E+02  .79405E+02  .80976E+02  .87030E+02  .96613E+02
.10285E+03  .97036E+02  .89203E+02  .68315E+02  .77215E+02  .76531E+02
.72488E+02  .83454E+02  .79676E+02  .86888E+02  .87819E+02  .79562E+02
.72595E+02  .72507E+02  .64512E+02  .10200E+03  .10904E+03
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      PROGRAM UHDSV
C THIS IS A MAIN PROGRAM FOR HEAT LOSS ANALYSIS OF SHALLOW TRENCH
C UNDERGROUND HEAT DISTRIBUTION SYSTEMS WITH VERTICAL PIPE SUPPORTS
C BASE ON THE FINITE ELEMENT METHOD USING THREE - NODE LINEAR
C TRIANGULAR ELEMENTS.
C SUBROUTINES CALLED: PIPEV, TGO,SOILK,INSULK,TGXX,SOLVLE,PIPEHL,TWOPIP.
C     INPUT DATA FILES: DATAV1 AND DATAV2
C     X(I): THE X-COORDINATE OF NODAL POINT I,IN FT
C     Y(I): THE Y-COORDINATE OF NODAL POINT I,IN FT
C     (NODE(M,I),I=1,3): THREE NODAL POINTS OF ELEMENT M
C     M      ELEMENT INDEX
C     NE     TOTAL NUMBER OF ELEMENTS
C     NN     TOTAL NUMBER OF NODAL POINTS
C     MZ     TOTAL NUMBER OF KNOWN NODAL TEMPERATURES
C     C      THERMAL CONDUCTIVITY, BTU-IN/HR/FT**2/DEG F
C     L      THICKNESS OF THE ELEMENT, FT
C     T(I): THE TEMPERATURE OF NODAL POINT I, IN DEG F
      REAL L,KK,KI,KG,KIX1,KIX2,KTCT,KASP,KS
      CHARACTER*4 TITLE(15)
      DIMENSION Q(150),T(150),X(150),Y(150),KK(150,150)
      DIMENSION AS(250),B2IZ(250),B3IZ(250),B2JZ(250),B2KZ(250),
     & B3JZ(250),B3KZ(250)
      DIMENSION CC(250),TGX(12,5),QQ(150),NODE(250,3),MAT(250)
      DIMENSION HIJ(250),HJK(250),HKI(250),TIJ(250),TJK(250),
     & TKI(250),HHIJ(250),HHJK(250),HHKI(250),IXCB(250)
      DIMENSION CK(150,150),DQ(150),XT(150),INDX(150),VV(150)
      COMMON/PP/TP1,TP2,KI,KG,D1,D2,TH1,TH2,DP1,DP2,S1,S2,TG,
     & WW,HY,MONTH,KS,ST1,ST2,FT1,FT2
      COMMON /EK/D1P,D2P,A,B,THK1,THK2
      COMMON /ST/AO,BO,DIFF
      PI=4.*ATAN(1.)
      OPEN (8,FILE='DATAV1')
      OPEN (7,FILE='OTFILEV',STATUS='NEW',FORM='FORMATTED')
      OPEN (9,FILE='DATAV2')
C  READ IN THE TITLE OF THE PROBLEM TO BE ANALYZED
      READ (8,2,ERR=2000) TITLE
2     FORMAT(15A4)
      WRITE (7,3) TITLE
3     FORMAT(1X,15A4)
C  READ TOTAL NUMBER OF NODAL POINTS, TOTAL NUMBER OF TRIANGULAR
C  ELEMENTS, TOTAL NUMBER OF KNOWN NODAL TEMPERATURES, AND THE
C  FIRST ELEMENT INDEX OF PIPE INSULATION
      READ (8,*) NN,NE,MZ,MINS
C  READING IN THE TYPE OF UNDERGROUND SYSTEMS TO BE ANALYZED :
C          ITREN = 1 FOR SHALLOW TRENCH
C                = 0 FOR LOOSE-FILL INSULATION
      READ (8,*) ITREN
C  SET THE UNIT NUMBER OF THE PRINTER
      MO=7
C  READ MONTH OF INTEREST AND THE INDEX FOR FINITE ELEMENT GRID DATA
C  TO BE PRINTED OUT : ICALB = 1  PRINT OUT NODAL COORDINATES
C                            = 0  NO PRINT OUT
      READ (8,*) MONTH,ICALB
      IF(ITREN.EQ.1) THEN
C   READ THE THERMAL CONDUCTIVITY (IN BTU-IN./H-FT**2 - DEG F) AND
C   THICKNESS (IN INCHES) OF CONCRETE WALL, AND THE THICKNESS OF
C   CONCRETE TRENCH COVER (IN FT.) AND THE THICKNESS OF CONCRETE
C   FLOOR (IN FT. ) FOR SHALLOW TRENCH SYSTEMS.
        READ (8,*) KTCT,TRTK,D,F
C   READ THE ESTIMATED AVERAGE TEMPERATURE OF AIR INSIDE THE SHALLOW
C   TRENCH, IN DEG F, AND THE TEMPERATURE DIFFERENCE BETWEEN THE
C   EFFECTIVE PIPE SURFACE TEMPERATURE AND THE INNER SURFACE
C   TEMPERATURE OF THE TRENCH, IN DEG F
        READ (8,*) TAS,TDEL
      ELSE
C  READING IN THERMAL CONDUCTIVITY AND THICKNESS (IN INCHES) OF SOIL
C  IN INNER EARTH REGION, AND THE DEPTH OF EARTH COVER (IN FT.).
        READ (8,*) KTCT,TRTK,D
C  READ IN THE THERMAL CONDUCTIVITY OF POURED-IN INSULATION MATERIAL
C  SURROUNDING THE PIPES FOR LOOSE-FILL INSULATION SYSTEMS
        READ (8,*) KASP
      END IF
C  READING IN INPUT DATA FOR CALCULATIONS OF PIPE HEAT LOSS AND
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C  GENERATION OF THE COORDINATES OF NODAL POINTS
      CALL PIPEV(X,Y,ITREN,TRTK,D,F,INXK)
      CALL TWOPIP(1,ITREN)
      CALL EQUIK(TAS,TDEL,KASP)
      IF(ICALB.EQ.1) THEN
      WRITE(7,5)
5     FORMAT('  X(M),M=1,NN')
      WRITE(7,7) (X(I),I=1,NN)
7     FORMAT(10F7.2)
      WRITE(7,10)
10    FORMAT('  Y(M),M=1,NN')
      WRITE(7,7) (Y(I),I=1,NN)
      END IF
C  CALCULATIONS OF UNDISTURBED EARTH TEMPERATURES AT VARIOUS DEPTHS
      CALL TGO(TGX,PI,Y)
C  INITIALIZATION OF THE INDEX OF CONVECTION BOUNDARY FOR ELEMENT N
      DO 12 N=1,NE
12    IXCB(N)=0
C  PERFORM ITERATIONS TO ACCOUNT FOR THE TEMPERATURE EFFECTS ON SOIL
C  AND INSULATION THERMAL CONDUCTIVITIES
        DO 24 I=1,NN
24          T(I)=TG
       DO 26 I=1,NE
          HIJ(I)=0.
          HJK(I)=0.
          HKI(I)=0.
          TIJ(I)=0.
          TJK(I)=0.
          TKI(I)=0.
          HHIJ(I)=0.
          HHJK(I)=0.
          HHKI(I)=0.
26      CONTINUE
C     READING IN THE ELEMENT NUMBER AND ITS NODAL POINTS AND THE
C     MATERIAL TYPE, WHICH INCLUDES
C         MAT(J) = 1  CONCRETE TRENCH
C                = 2  PIPE INSULATION
C                = 3  AIR SPACE SURROUNDING THE PIPES IN TRENCH
C                = 4  SOIL SURROUNDING THE TRENCH
C                = 5  STEEL PIPE SUPPORT OR BASE PLATE
      DO 30 I=1,NE
         READ(9,*) J,(NODE(J,K),K=1,3),MAT(J)
         IF (MAT(J).EQ.1) CC(J)=KTCT/12.
         IF (MAT(J).EQ.2) CC(J)=KI/12.
         IF (MAT(J).EQ.3) CC(J)=KASP/12.
         IF (MAT(J).EQ.4) CC(J)=KG/12.
         IF (MAT(J).EQ.5) CC(J)=KS/12.
30    CONTINUE
C   READ IN TOTAL NUMBER OF ELEMENTS HAVING BOUNDARY SEGMENTS SUBJECT
C   TO CONVECTIVE HEAT TRANSFER
      READ (9,*) NECB
C   READ IN ELEMENT NUMBER, CONVECTIVE HEAT TRANSFER COEFFICIENTS,
C   AND AMBIENT TEMPERATURES FOR THREE BOUNDARY SEGMENTS
      DO 35 I=1,NECB
        READ (9,*) M,HIJ(M),HJK(M),HKI(M),TIJ(M),TJK(M),TKI(M)
        IXCB(M)=1
35    CONTINUE
      ITER=1
38    DO 40 I=1,NN
      DO 40 J=1,NN
          Q(I)=0.
          KK(I,J)=0.
          QQ(I)=0.
          CK(I,J)=0.
          DQ(I)=0.
          VV(I)=1.0
          INDX(I)=1
40    CONTINUE
      L=1.
      DO 180 M=1,NE
        I=NODE(M,1)
        J=NODE(M,2)
        K=NODE(M,3)
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      IF (MAT(M).EQ.3) CC(M)=KASP/12.
      C=CC(M)
      IF ((INXK.EQ.0).OR.(ITER.EQ.1)) GO TO 60
C  DETERMINE SOIL AND INSULATION THERMAL CONDUCTIVITIES BASED ON THE
C  MEAN TEMPERATURES
      TM=(T(I)+T(J)+T(K))/3.
      IF(MAT(M).EQ.2)  CALL INSULK(TM,C)
      IF(MAT(M).EQ.4)  CALL SOILK(TM,KG,C)
      CC(M)=C
60    XI=X(I)
      XJ=X(J)
      XK=X(K)
      YI=Y(I)
      YJ=Y(J)
      YK=Y(K)
      CXX=C
      CXY=0.
      CYX=0.
      CYY=C
      B2I=YJ-YK
      B3I=XK-XJ
      B2J=YK-YI
      B3J=XI-XK
      B2K=YI-YJ
      B3K=XJ-XI
C   CALCULATE THE ELEMENT AREA
      SA=0.5*(XJ*B2J+XI*B2I+XK*B2K)
      SA=ABS(SA)
      A2=SA*2.
      AS(M)=A2
      B2I=B2I/A2
      B3I=B3I/A2
      B2J=B2J/A2
      B3J=B3J/A2
      B2K=B2K/A2
      B3K=B3K/A2
      B2IZ(M)=B2I
      B3IZ(M)=B3I
      B2JZ(M)=B2J
      B3JZ(M)=B3J
      B2KZ(M)=B2K
      B3KZ(M)=B3K
      BII=SA*L*(B2I*B2I*CXX+B2I*B3I*CXY+B3I*B2I*CYX+B3I*B3I*CYY)
      BIJ=SA*L*(B2I*B2J*CXX+B2I*B3J*CXY+B3I*B2J*CYX+B3I*B3J*CYY)
      BIK=SA*L*(B2I*B2K*CXX+B2I*B3K*CXY+B3I*B2K*CYX+B3I*B3K*CYY)
      BJI=SA*L*(B2J*B2I*CXX+B2J*B3I*CXY+B3J*B2I*CYX+B3J*B3I*CYY)
      BJJ=SA*L*(B2J*B2J*CXX+B2J*B3J*CXY+B3J*B2J*CYX+B3J*B3J*CYY)
      BJK=SA*L*(B2J*B2K*CXX+B2J*B3K*CXY+B3J*B2K*CYX+B3J*B3K*CYY)
      BKI=SA*L*(B2K*B2I*CXX+B2K*B3I*CXY+B3K*B2I*CYX+B3K*B3I*CYY)
      BKJ=SA*L*(B2K*B2J*CXX+B2K*B3J*CXY+B3K*B2J*CYX+B3K*B3J*CYY)
      BKK=SA*L*(B2K*B2K*CXX+B2K*B3K*CXY+B3K*B2K*CYX+B3K*B3K*CYY)
      KK(I,I)=KK(I,I)+BII
      KK(I,J)=KK(I,J)+BIJ
      KK(I,K)=KK(I,K)+BIK
      KK(J,I)=KK(J,I)+BJI
      KK(J,J)=KK(J,J)+BJJ
      KK(J,K)=KK(J,K)+BJK
      KK(K,I)=KK(K,I)+BKI
      KK(K,J)=KK(K,J)+BKJ
      KK(K,K)=KK(K,K)+BKK
      IF(IXCB(M).EQ.0) GO TO 130
C   ADDITION OF CONVECTION TERMS TO THE ELEMENT MATRIX TO ACCOUNT
C   FOR CONVECTION ON BOUNDARY
C   READING IN CONVECTIVE HEAT TRANSFER COEFFICIENTS AND AMBIENT
C   TEMPERATURES FOR THREE BOUNDARY SEGMENTS
      HHIJ(M)=HIJ(M)*L*SQRT((X(I)-X(J))**2+(Y(I)-Y(J))**2)/6.
      HHJK(M)=HJK(M)*L*SQRT((X(J)-X(K))**2+(Y(J)-Y(K))**2)/6.
      HHKI(M)=HKI(M)*L*SQRT((X(K)-X(I))**2+(Y(K)-Y(I))**2)/6.
      KK(I,I)=HHIJ(M)*2.+HHKI(M)*2.+KK(I,I)
      KK(I,J)=HHIJ(M)+KK(I,J)
      KK(I,K)=HHKI(M)+KK(I,K)
      KK(J,I)=HHIJ(M)+KK(J,I)
      KK(J,J)=HHIJ(M)*2+HHJK(M)*2.+KK(J,J)
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      KK(J,K)=HHJK(M)+KK(J,K)
      KK(K,I)=HHKI(M)+KK(K,I)
      KK(K,J)=HHJK(M)+KK(K,J)
      KK(K,K)=HHJK(M)*2.+HHKI(M)*2.+KK(K,K)
      HHIJ(M)=TIJ(M)*3.*HHIJ(M)
      HHJK(M)=TJK(M)*3.*HHJK(M)
      HHKI(M)=TKI(M)*3.*HHKI(M)
130   Q(I)=Q(I)+HHIJ(M)+HHKI(M)
      Q(J)=Q(J)+HHIJ(M)+HHJK(M)
      Q(K)=Q(K)+HHJK(M)+HHKI(M)
180   CONTINUE
C   DETERMINE IF FINITE ELEMENT GRID DATA ARE TO BE PRINTED OUT
      IF ((ICALB.EQ.1).AND.(ITER.EQ. 3 )) THEN
      WRITE(7,185)
185   FORMAT('       M      I      J      K     MAT.     C')
      DO 190 I=1,NE
      WRITE(7,187) I,(NODE(I,J),J=1,3),MAT(I),CC(I)
187   FORMAT(1X,5I6,F10.4)
190   CONTINUE
      END IF
C   DETERMINE OUTER SURFACE TEMPERATURES OF UNDERGROUND PIPES
      DO 200 I=1,8
        T(I)=TP1
        II=I+8
        T(II)=TP2
200   CONTINUE
      DO 202 I=1,2
         I16=I+16
         I18=I+18
         T(I16)=TP1
         T(I18)=TP2
202    CONTINUE
C   DETERMINE OUTER BOUNDARY TEMPERATURES OF EARTH REGION
      CALL TGXX(T,TGX,MONTH)
      MZ1=MZ+1
      DO 260 I=MZ1,NN
        SUM=0.
        DO 250 J=1,MZ
250       SUM=SUM+KK(I,J)*T(J)
        QQ(I)=Q(I)-SUM
260   CONTINUE
      IF(ICALB.EQ.1) THEN
         WRITE(7,280)
280      FORMAT(6X,'QQ     ARRAY')
         WRITE(7,285) (QQ(I),I=1,NN)
285      FORMAT (6E12.5)
      END IF
C  RENAMING OF MATRICES
      MN=NN-MZ
      DO 300 I=1,MN
         K=MZ+I
        DO 290 J=1,MN
            KL=MZ+J
290         CK(I,J)=KK(K,KL)
            XT(I)=T(K)
            DQ(I)=QQ(K)
300      CONTINUE
C  SOLUTION OF SIMULTANEOUS EQUATIONS
C  SET PHYSICAL DIMENSION OF MATRIX A
       NP=150
      CALL SOLVLE(CK,MN,NP,INDX,VV,DQ)
      DO 310 I=1,MN
          K=MZ+I
          T(K)=DQ(I)
310    CONTINUE
C  CALCULATE THE AVERAGE SURFACE TEMPERATURE OF INSULATED PIPES
       SU1=0.
       SU2=0.
       DO 312 I=1,8
         L1=I+73
         L2=I+81
         SU1=SU1+T(L1)
         SU2=SU2+T(L2)
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312     CONTINUE
        TSM1=SU1/8.
        TSM2=SU2/8.
C  DETERMINE THE EFFECTIVE SURFACE TEMPERATURE OF INSULATED
C  PIPES, IN DEG F
        DIP1=D1P+2.*THK1
        DIP2=D2P+2.*THK2
        TEFPS=(DIP1*TSM1+DIP2*TSM2)/(DIP1+DIP2)
C  CALCULATE THE INNER SURFACE TEMPERATURE OF THE TRENCH
        SU3=0.
        DO 314 I=1,14
           L3=I+40
314     SU3=SU3+T(L3)
        TEFTS=SU3/14.
C  DETERMINE THE TEMPERATURE DIFFERENCE BETWEEN THE EFFECTIVE
C  SURFACE TEMPERATURE OF INSULATED PIPES AND THE INNER
C  SURFACE TEMPERATURE OF THE TRENCH, IN DEG F, AND BULK AIR
C  TEMPERATURE
        TDEL=ABS(TEFPS-TEFTS)
        TAS=(TEFPS+TEFTS)/2.
C  CALCULATE THE EFFECTIVE THERMAL CONDUCTIVITY OF AIR SPACE
        CALL EQUIK(TAS,TDEL,KASP)
        WRITE (7,316) KASP
316    FORMAT('  KASP=',F10.4,2X,'(BTU-IN./H-FT**2-DEG F)')
330    FORMAT('  TEMPERATURE ARRAY : T(I), I=1,NN ')
C  CALCULATE THE MEAN VALUES OF INSULATION THERMAL CONDUCTIVITY FOR
C  PIPES 1 AND 2
350    SKI1=0.
       SKI2=0.
       DO 400 LN=1,16
          LM=MINS+LN-1
          LL=LM+16
          SKI1=SKI1+CC(LM)
          SKI2=SKI2+CC(LL)
400    CONTINUE
       KIX1=SKI1/16.
       KIX2=SKI2/16.
       R1=D1/24.
       R2=D2/24.
       TH1X=TH1/12.
       TH2X=TH2/12.
       IF(ICALB .EQ. 0) THEN
         MO=11
         IF(ITER .EQ. 3) MO=7
       END IF
C  CALCULATIONS OF THE HEAT LOSSES FROM THE UNDERGROUND PIPES
       CALL  PIPEHL(T,R1,R2,TH1X,TH2X,KIX1,KIX2,KS,ST1,ST2,MO,QTX)
       HLOSS=QTX
       IF (ITER.EQ. 1) HLOSX=0.
C  DETERMINE IF PIPE HEAT LOSS VALUE HAS CONVERGED OR CONTINUE
C  ITERATIONS IF REQUIRED
       DELQT=ABS(HLOSS-HLOSX)/HLOSS
       IF (DELQT .LE. 0.005) GO TO 2010
       ITER=ITER+1
       HLOSX=HLOSS
       GO TO 38
2000   WRITE (7,2005)
2005   FORMAT (1X,'THERE ARE SOME ERRORS IN INPUT DATA')
2010   IF (ICALB.EQ.1) THEN
       WRITE (7,330)
       WRITE (7,285) (T(I),I=1,NN)
       END IF
       STOP
       END

       SUBROUTINE TGO(TGX,PI,Y)
C   THIS SUBROUTINE CALCULATES THE UNDISTURBED EARTH TEMPERATURES
C   AT VARIOUS DEPTHS
       DIMENSION TGX(12,5),Y(150)
C      READING IN THE ANUAL AVERAGE TEMPERATURE AND AMPLITUDE OF THE
C      MONTHLY NORMAL TEMPERATURE CYCLE OF THE SITE, IN DEG F, AND
C      THERMAL DIFFUSIVITY OF SOIL, IN FT**2/H.
       READ (8,*) AO,BO,DIFF
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      W=2.*PI/12.
      WZ=2.*PI/(8760*DIFF*2)
      ZZ=SQRT(WZ)
      DO 1 I=1,12
      DO 1 J=1,5
      Z=ZZ*Y(33-J)
1     TGX(I,J)=AO+BO*EXP(-Z)*SIN(W*(I-3)-Z)
      RETURN
      END

      SUBROUTINE TGXX(T,TGX,MONTH)
C THIS SUBROUTINE PROVIDES OUTER BOUNDARY TEMPERATURES OF EARTH REGION
      DIMENSION T(150),TGX(12,5)
      T(32)=TGX(MONTH,1)
      DO 1 I=1,8
         II=I+32
1        T(II)=T(32)
      DO 5 I=2,5
         I19=I+19
         JI=33-I
         T(I19)=TGX(MONTH,I)
         T(JI)=TGX(MONTH,I)
5     CONTINUE
      DO 10 I=1,3
         I24=I+24
10     T(I24)=TGX(MONTH,5)
      RETURN
      END

      SUBROUTINE INSULK(TM,C)
C  THIS SUBROUTINE DETERMINES THE THERMAL CONDUCTIVITY OF PIPE
C  INSULATION (CALCIUM SILICATE) AS A FUNCTION OF THE MEAN
C  TEMPERATURE.
      REAL KN(16),KINS
      DIMENSION TN(16)
      DATA KN /0.375,0.40,0.42,0.45,0.48,0.50,0.53,0.555,0.58,0.61,
     & 0.63,0.66,0.68,0.74,0.82,0.90/
      DO 5 J=1,16
      IF(J .LE. 13) THEN
         TN(J)=100.+(J-1)*50.
      ELSE
         TN(J)=700.+(J-13)*100.
      END IF
5     CONTINUE
      IF(TM .GT. TN(1)) GO TO 10
      KINS=KN(1)
      GO TO 100
10    IF(TM .LT. TN(16)) GO TO 20
      KINS=KN(16)
      GO TO 100
20    DO 50 I=1,15
      T1=TM-TN(I)
      IF(T1 .NE. 0.) GO TO 30
      KINS=KN(I)
      GO TO 100
30    T2=TN(I+1)-TM
      IF(T2 .NE. 0.) GO TO 40
      KINS=KN(I+1)
      GO TO 100
40    P=T1*T2
      IF(P .LT. 0.) GO TO 50
      KINS=KN(I)+T1*(KN(I+1)-KN(I))/(TN(I+1)-TN(I))
      GO TO 100
50    CONTINUE
100   C=KINS/12.
      RETURN
      END

      SUBROUTINE  SOILK(TM,KG,C)
C THIS ROUTINE DETERMINES THE THERMAL CONDUCTIVITY OF SOIL AS A
C FUNCTION OF MEAN TEMPERATURES.
      REAL K(14),KG
      DIMENSION TX(14)
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      DATA K/1.1,1.1,1.1,1.0,0.4,0.31,0.25,0.19,0.15,0.11,0.09,0.07,
     & 0.05,0.05/
      DO 1 I=1,14
1        TX(I)=50.+(I-1)*25.
      IF(TM.GT.TX(1)) GO TO 5
      ZK=1.1
      GO TO 50
5     IF(TM.LT.TX(14)) GO TO 10
      ZK=0.05
      GO TO 50
10    DO 25 I=1,13
      T1=TM-TX(I)
      IF(T1.NE.0) GO TO 15
      ZK=K(I)
      GO TO 50
15    CONTINUE
      T2=TM-TX(I+1)
      IF(T2.NE.0.) GO TO 20
      ZK=K(I+1)
      GO TO 50
20    CONTINUE
      P=T1*T2
      IF(P.GT.0) GO TO 25
      ZK=K(I+1)+T2*(K(I+1)-K(I))/25.
      GO TO 50
25    CONTINUE
50    C=ZK*KG/(1.1*12.)
      RETURN
      END

      SUBROUTINE PIPEHL(T,R1,R2,TH1,TH2,ZKS1,ZKS2,ZKS,ST1,ST2,MO,QT)
C  THIS SUBROUTINE CALCULATES THE AVERAGE TEMPERATURE DROPS ACROSS THE
C  PIPE INSULATIONS AND THE RATES OF HEAT LOSS FROM THE UNDERGROUND
C  PIPES IN TRENCH SYSTEM
      DIMENSION T(150)
      PI=4.*ATAN(1.)
C  HEAT LOSSES THROUGH PIPE SUPPORTS
      RA1=ST1/(2.*R1)
      RA2=ST2/(2.*R2)
      OMEG1=2.*ASIN(RA1)
      OMEG2=2.*ASIN(RA2)
      DTS1=(T(17)+T(8)+T(18))-(T(104)+T(81)+T(105))
      DTS2=(T(19)+T(16)+T(20))-(T(106)+T(89)+T(107))
      ZKST=ZKS/12.
      Q1S=ZKST*OMEG1*DTS1/LOG((R1+TH1)/R1)
      Q2S=ZKST*OMEG2*DTS2/LOG((R2+TH2)/R2)
C  HEAT LOSSES THROUGH PIPE INSULATION
      SUM1=0.
      SUM2=0.
      N1=7
      DO 1 I=1,N1
         K1=I
         K2=I+8
         K3=I+73
         K4=I+81
         SUM1=SUM1+T(K1)-T(K3)
         SUM2=SUM2+T(K2)-T(K4)
1     CONTINUE
      T1=SUM1/N1
      T2=SUM2/N1
      ZKIS1=ZKS1*12.
      ZKIS2=ZKS2*12.
      Q1A=ZKS1*1.5*PI*T1/LOG((R1+TH1)/R1)
      Q2A=ZKS2*1.5*PI*T2/LOG((R2+TH2)/R2)
      DTI1=(T(7)+T(17)+T(18)+T(1))-(T(80)+T(104)+T(105)+T(74))
      DTI2=(T(15)+T(19)+T(20)+T(9))-(T(88)+T(106)+T(107)+T(82))
      Q1B=ZKS1*(0.5*PI-OMEG1)*DTI1/LOG((R1+TH1)/R1)
      Q2B=ZKS2*(0.5*PI-OMEG2)*DTI2/LOG((R2+TH2)/R2)
C  COMBINED PIPE HEAT LOSSES
      Q1=Q1A+Q1B+Q1S
      Q2=Q2A+Q2B+Q2S
      QT=Q1+Q2
      IF(MO .EQ. 11) GO TO 50
```

```
      WRITE(MO,5) ZKIS1,ZKIS2
5     FORMAT(/'  AVERAGE VALUES OF PIPE INSULATION THERMAL',
     &' CONDUCTIVITY :',/,'   KI1 = ',F10.3,'   KI2 = ',F10.3,
     & '   BTU-IN/H-FT**2-DEG F ')
      WRITE(MO,10) T1,T2
10    FORMAT(/'  AVERAGE TEMPERATURE DROPS ACROSS INSULATION : ',/,
     & '    T1= ',F10.2,'   T2= ',F10.2,'  DEG F')
      WRITE(MO,20) Q1,Q2,QT
20    FORMAT(/,2X,'HEAT LOSSES FROM UNDERGROUND PIPES :'/'   Q1=',
     & F10.2, '   Q2=',F10.2,'   QT=',F10.2,'  BTU/H-FT')
50    RETURN
      END

      SUBROUTINE PIPEV(X,Y,ITREN,TRTK,D,F,INXK)
C THIS SUBROUTINE READS IN THE INPUT DATA TO BE USED FOR CALCULATIONS
C OF THE HEAT LOSSES FROM THE UNDERGROUND PIPES AND GENERATES X AND Y-
C COORDINATES OF NODAL POINTS FOR THE TWO PIPE SYSTEM.
      REAL KII,KIG,KI,KG,KS
      DIMENSION X(150),Y(150)
      COMMON /PP/TP1,TP2,KII,KIG,DI1,DI2,THI1,THI2,B1,B2,S1,S2,TG,
     & WW,HY,MONTH,KS,ST1,ST2,FT1,FT2
      COMMON /EK/D1P,D2P,A,B,THK1,THK2
C READ TEMPERATURE OF PIPE NUMBERS 1 2, IN DEG F
      READ (8,*) TP1,TP2
C READ THERMAL CONDUCTIVITY OF THERMAL INSULATION,SOIL,AND PIPE
C SUPPORT, IN BTU-IN./H-FT**2 - DEG F,AND INDEX OF THERMAL
C CONDUCTIVITY : INXK = 0  CONSTANT THERMAL CONDUCTIVITY
C                     = 1  TEMPERATURE DEPENDENT THERMAL CONDUCTIVITY
      READ (8,*) KII,KIG,KS,INXK
C READING IN THE OUTSIDE DIAMETERS OF STEEL PIPES 1 AND 2, IN INCHES
      READ (8,*) DI1,DI2
C READING IN THE THICKNESS OF THERMAL INSULATION USED FOR PIPES 1
C AND 2, RESPECTIVELY, IN INCHES
      READ (8,*) THI1,THI2
C READ THE DEPTHS FROM GROUND SURFACE TO THE CENTERS OF PIPES 1 AND
C 2, RESPECTIVELY, IN FT.
      READ (8,*) B1,B2
C   READING IN THE HORIZONTAL DISTANCES (IN FT.) FROM VERTICAL
C   CENTERLINE OF THE TRENCH TO CENTERS OF PIPES 1 AND 2,
C   RESPECTIVELY, AND THE AVERAGE EARTH TEMPERATURE, IN DEG F.
      READ (8,*) S1,S2,TG
C   READ IN THE WIDTH AND DEPTH OF EARTH REGION SURROUNDING THE
C   UNDERGROUND SYSTEM, IN FT.
      READ (8,*) WW,HY
C   READ IN THE HEIGHTS,WIDTHS,AND STEM AND FLANGE THICKNESSES
C   OF PIPE SUPPORTS 1 AND 2, RESPECTIVELY, IN INCHES.
      READ(8,*) SH1,SH2,SW1,SW2,ST1,ST2,FT1,FT2
C   READ IN THE THICKNESS AND WIDTH OF THE BASE PLATE, IN INCHES.
      READ(8,*) BPT,BPW
C   READ IN THE HEIGHT AND WIDTH OF THE WALL PLATES, IN INCHES.
      READ(8,*) PH,PW
      WRITE(7,10) TP1,TP2,KII,KIG,DI1,DI2
10    FORMAT('   TP1    TP2     KI     KG     D1     D2'/6F7.2)
      WRITE(7,20) THI1,THI2,B1,B2,S1,S2,TG
20    FORMAT('   THI1   THI2    DP1    DP2     S1     S2     TG',
     & /7F7.2)
      WRITE(7,30) WW,HY,MONTH
30    FORMAT('     WW     HY   MONTH '/2F7.2,I7)
      WRITE(7,32) SH1,SH2,SW1,SW2,ST1,ST2,FT1,FT2
32    FORMAT('     SH1    SH2    SW1    SW2    ST1    ST2    FT1    FT2',
     &/8F7.3)
      WRITE(7,35) BPT,BPW, PH, PW
35    FORMAT('     BPT    BPW     PH     PW',/4F8.3)
C   READ IN THE INNER WIDTH AND HEIGHT OF THE TRENCH, OR THE WIDTH
C   AND HEIGHT OF THE INNER EARTH REGION FOR LOOSE-FILL INSULATION
C   SYSTEMS, IN FT.
      READ (8,*) A,B
C   CHANGE TO ENGINEERING UNITS
      D1=DI1/12.
      R1=D1*0.5
      D2=DI2/12.
      R2=D2*0.5
      D1P=DI1/12.
```

```
      D2P=DI2/12.
      SH1=SH1/12.
      SH2=SH2/12.
      SW1=SW1/12.
      SW2=SW2/12.
      ST1=ST1/12.
      ST2=ST2/12.
      FT1=FT1/12.
      FT2=FT2/12.
      BPT=BPT/12.
      BPW=BPW/12.
      PH=PH/12.
      PW=PW/12.
      KI=KII/12.
      KG=KIG/12.
      IF(ITREN .EQ. 1) THEN
        W=A+2*TRTK/12
        H=B+D+F
      ELSE
        W=2*A
        H=2.*B+D
      END IF
      WRITE(7,40) W,H,D,F,A,B,WW,HY
40    FORMAT('     W      H      D      F      A      B      WW      HY'
     &,/,8F7.2)
      PI=4.*ATAN(1.)
      TH1=THI1/12.
      TH2=THI2/12.
      THK1=THI1/12.
      THK2=THI2/12.
C   DETERMINE THE X AND Y-COORDINATES OF CONCRETE TRENCH COVER,
C   WALLS,AND FLOOR (NODAL POINTS 34 TO 38, AND 41 TO 65)
      DO 50 I=1,5,2
        I33=I+33
        X(I33)=W-(I-1)*W/4.
50      Y(I33)=0.
      DO 60 I=1,3,2
        I34=I+34
        X(I34)=(W+A)*0.5 - A*(I-1)*0.5
60      Y(I34)=0.
      DO 62 I=1,3
        I40=I+40
        I48=I+48
        I51=I+51
        I54=I+54
        I58=I+58
        I62=I+62
        X(I40)=(W-A)*0.5
        Y(I40)=D+(I-1)*B/4.
        X(I48)=(W+A)*0.5
        Y(I48)=D+0.5*B-(I-1)*B/4.
        X(I51)=0.5*(W+A)-I*A/4.
        Y(I51)=D
        X(I54)=0.
        Y(I54)=D+B*(I-1)/2.
        X(I58)=(W-A)*0.5+(I-1)*A/2.
        Y(I58)=D+B+F
        X(I62)=W
        Y(I62)=D+(3-I)*B/2.
62    CONTINUE
      DO 65 I=1,5
        I43=I+43
        X(I43)=0.5*(W-A)+(I-1)*A/4.
        Y(I43)=D+B
65     CONTINUE
        X(58)=0.
        Y(58)=D+B+F
        X(62)=W
        Y(62)=D+B+F
C   THE X AND Y-COORDINATES OF OUTER BOUNDARY EARTH SURROUNDING THE
C   SHALLOW TRENCH (NODAL POINTS 21 TO 33,39,40, AND 66 TO 73)
        X(21)=-WW
        Y(21)=0.5*H
```

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      X(31)=W+WW
      Y(31)=0.5*H
   DO 75 I=1,3
      I21=I+21
      I24=I+24
      I27=I+27
      X(I21)=-WW
      Y(I21)=H+HY*(I-1)*0.5
      X(I24)=W*(I-1)*0.5
      Y(I24)=H+HY
      X(I27)=W+WW
      Y(I27)=H+HY*(3-I)*0.5
75 CONTINUE
   DO 80 I=1,2
      I31=I+31
      I38=I+38
      I65=I+65
      I71=I+71
      X(I31)=W+WW*(3-I)*0.5
      Y(I31)=0.
      X(I38)=-WW*0.5*I
      Y(I38)=0.
      X(I65)=-WW*0.5
      Y(I65)=H*I*0.5
      X(I71)=W+WW*0.5
      Y(I71)=H*(3-I)*0.5
80 CONTINUE
   DO 85 I=1,4
      I67=I+67
      X(I67)=W*(I-1)/3.
85    Y(I67)=H+HY*0.5
C  X AND Y-COORDINATES OF THE CENTERS OF THE PIPES
   XC1=W*0.5 - S1
   YC1=B1
   XC2=W*0.5 + S2
   YC2=B2
   WRITE(7,90) XC1,YC1,XC2,YC2
90 FORMAT('    XC1    YC1    XC2    YC2'/4F7.3)
C  THE X AND Y-COORDINATES OF NODAL POINTS AT THE INNER SURFACES
C  OF PIPE INSULATION AND OUTER SURFACES OF THE INSULATED PIPES
C  (NODAL POINTS 1 TO 20, 74 TO 89, AND 104 TO 107)
   DO 95 I=1,8
      THETA=2.*PI*I/8.
      I8=I+8
      I73=I+73
      I81=I+81
      X(I)=XC1+0.5*D1*SIN(THETA)
      Y(I)=YC1+0.5*D1*COS(THETA)
      X(I8)=XC2+0.5*D2*SIN(THETA)
      Y(I8)=YC2+0.5*D2*COS(THETA)
      X(I73)=XC1+(TH1+0.5*D1)*SIN(THETA)
      Y(I73)=YC1+(TH1+0.5*D1)*COS(THETA)
      X(I81)=XC2+(TH2+0.5*D2)*SIN(THETA)
      Y(I81)=YC2+(TH2+0.5*D2)*COS(THETA)
95 CONTINUE
   BETA=3.*PI/8.
   X(17)=XC1-ST1*0.5
   Y(17)=YC1+0.5*(D1-ST1/TAN(BETA))
   X(18)=XC1+ST1*0.5
   Y(18)=Y(17)
   X(19)=XC2-ST2*0.5
   Y(19)=YC2+0.5*(D2-ST2/TAN(BETA))
   X(20)=XC2+ST2*0.5
   Y(20)=Y(19)
   X(104)=XC1-ST1*0.5
   Y(104)=YC1+TH1+0.5*(D1-ST1/TAN(BETA))
   X(105)=XC1+ST1*0.5
   Y(105)=Y(104)
   X(106)=XC2-ST2*0.5
   Y(106)=YC2+TH2+0.5*(D2-ST2/TAN(BETA))
   X(107)=XC2+ST2*0.5
   Y(107)=Y(106)
C  THE X AND Y-COORDINATES OF NODAL POINTS IN AIR SPACE SURROUNDING
```

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C    THE PIPES INSIDE THE TRENCH (NODAL POINTS 90 TO 103)
        YUP=0.5*(Y(77)-Y(53))
        YUPR=0.5*(Y(85)-Y(53))
        IF (YUPR.LT.YUP) YUP=YUPR
        XLT=0.5*(X(79)-X(43))
        XRT=0.5*(X(49)-X(83))
      DO 100 I=1,3
         I89=I+89
         X(I89)=0.5*(W+A)-0.25*A*I
         Y(I89)=D+YUP
100   CONTINUE
      DO 105 I=1,2
         I92=I+92
         I98=I+98
         X(I92)=0.5*(W-A)+XLT
         Y(I92)=D+B*I/4.
         X(I98)=D+(3-I)*B/4.
         Y(I98)=0.5*(W+A)-XRT
105   CONTINUE
         X(95)=XC1-0.5*SW1
         Y(95)=Y(8)+SH1-FT1
         X(96)=XC1+0.5*SW1
         Y(96)=Y(95)
         X(97)=XC2-0.5*SW2
         Y(97)=Y(16)+SH2-FT2
         X(98)=XC2+0.5*SW2
         Y(98)=Y(97)
         X(103)=0.5*W
         Y(103)=Y(8)+SH1
      DO 120 I=1,2
         II=I+100
         X(II)=X(53)
         Y(II)=(Y(103)-Y(91))*I/3.
120   CONTINUE
C   THE X AND Y-COORDINATES OF NODAL POINTS IN STEEL PIPE SUPPORTS
C   AND BASE AND WALL PLATES (NODAL POINTS 108 TO 132)
        X(108)=XC1-0.5*ST1
        Y(108)=Y(95)
        X(109)=XC1+0.5*ST1
        Y(109)=Y(108)
        X(110)=XC2-0.5*ST2
        Y(110)=Y(97)
        X(111)=XC2+0.5*ST2
        Y(111)=Y(110)
        X(112)=(W-A)*0.5
        Y(112)=Y(8)+SH1
        X(113)=XC1-0.5*SW1
        Y(113)=Y(8)+SH1
        X(114)=XC1+0.5*ST1
        Y(114)=Y(112)
        X(115)=XC1+0.5*SW1
        Y(115)=Y(112)
        X(116)=XC2-0.5*SW2
        Y(116)=Y(16)+SH2
        X(117)=XC2-0.5*ST2
        Y(117)=Y(115)
        X(118)=XC2+0.5*SW2
        Y(118)=Y(116)
        X(119)=(W+A)*0.5
        Y(119)=Y(118)
      DO 130 I=1,5
        II=I+119
        X(II)=(W-A)*0.5+(I-1)*A/4.
130     Y(II)=Y(8)+SH1+BPT
        X(125)=(W-A)*0.5
        Y(125)=Y(8)+SH1-0.5*(PH-BPT)
        X(126)=(W-A)*0.5
        Y(126)=Y(8)+SH1+0.5*(PH+BPT)
        X(127)=(W+A)*0.5
        Y(127)=Y(16)+SH2+0.5*(PH+BPT)
        X(128)=(W+A)*0.5
        Y(128)=Y(16)+SH2-0.5*(PH-BPT)
        X(129)=(W-A)*0.5-PW
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      Y(129)=Y(125)
      X(130)=(W-A)*0.5-PW
      Y(130)=Y(126)
      X(131)=(W+A)*0.5+PW
      Y(131)=Y(127)
      X(132)=(W+A)*0.5+PW
      Y(132)=Y(128)
      RETURN
      END

      SUBROUTINE TWOPIP(IREPT,ITREN)
C  THIS SUBROUTINE DETERMINES THE HEAT LOSSES FROM TWO PIPES TO THE
C  UNDERGROUND SURROUNDING THE HEAT DISTRIBUTION SYSTEM.
      REAL KII,KIG,KS
      COMMON /PP/T1,T2,KII,KIG,DI1,DI2,THI1,THI2,B1,B2,S1,S2,TG,
     & WW,HY,MONTH,KS,ST1,ST2,FT1,FT2
      PI=4.*ATAN(1.)
      X1=2.*PI
      R1=DI1/24.
      R2=DI2/24.
      TH1X=THI1/12.
      TH2=THI2/12.
      ZK1=KII/12.
      ZK2=ZK1
      D1=B1
      D2=B2
      ZKS=KIG/12.
      DO 10 I=1,IREPT
2     TH1=TH1X+0.1*(I-1)
      TH2=TH1
      S=S1+S2
      A=R1+R2+TH1+TH2+0.05
      THI1=TH1*12.
      IF(ITREN.EQ.1) A=S
      C1=X1*ZK1/LOG((R1+TH1)/R1)
      C2=X1*ZK2/LOG((R2+TH2)/R2)
      P11=1.+C1/(X1*ZKS)*LOG((2*D1)/(R1+TH1))
      P12=C2/(X1*ZKS)*LOG((A*A+(D1+D2)**2)/(A*A+(D1-D2)**2))*0.5
      P21=C1/(X1*ZKS)*LOG((A*A+(D1+D2)**2)/(A*A+(D1-D2)**2))*0.5
      P22=1.+C2/(X1*ZKS)*LOG((2*D2)/(R2+TH2))
      DEL=P12*P21-P11*P22
      ZKP1=C1*(P12-P22)/DEL
      ZKP2=C2*(P21-P11)/DEL
      TP1=(P12*T2-P22*T1)/(P12-P22)
      TP2=(P21*T1-P11*T2)/(P21-P11)
      Q1=ZKP1*(TP1-TG)
      Q2=ZKP2*(TP2-TG)
      QT=Q1+Q2
      TAVG=(T1+T2)*0.5
      ZK=QT/(TAVG-TG)
      WRITE(7,6) DI1,DI2,S1,S2,THI1,KII,KIG,T1,T2
6     FORMAT('   DI1   DI2    S1    S2  THI1   KII   KIG   TP1   TP2',
     &/,7F6.2,1X,2F6.0)
      WRITE(7,8) Q1,Q2,QT,ZK
8     FORMAT('    Q1    Q2     QT       KP'/,3F7.2,2X,F6.3/)
10    CONTINUE
      RETURN
      END

      SUBROUTINE EQUIK(TAS,TDEL,KASP)
C   THIS ROUTINE CALCULATES EQUIVALENT THERMAL CONDUCTIVITY OF AIR
C   SPACE SURROUNDING THE PIPES IN A SHALLOW TRENCH
      REAL KASP
      COMMON /EK/D1P,D2P,A,B,THK1,THK2
      PI=4.*ATAN(1.)
C   CALCULATE THERMAL CONDUCTIVITY, IN BTU-FT/H-FT**2-DEG F, AND
C   KINEMATIC VISCOSITY, IN FT**2/S, OF AIR
      THKAIR=0.01319 + TAS*2.5E -5
      VAIR=1.2624E -4 + TAS*5.4E -7
C   CALCULATE THE EFFECTIVE DIAMETERS OF THE RECTANGULAR TRENCH
C   AND THE INSULATED PIPES, IN FT, AND THE CHARACTERISTIC LENGTH
C   OF AIR SPACE, IN FT
      DEFTRN=2.0 * (A+B)/PI
```

```
      DEFPIP=(D1P+2.*THK1)+(D2P+2.*THK2)
      CL=DEFTRN - DEFPIP
C   CALCULATE THE PRANDTL NUMBER OF AIR , AND GRASHOF NUMBER AND
C   EQUIVALENT THERMAL CONDUCTIVITY, IN BTU-IN/H-FT**2-DEG F, OF
C   AIR SPACE
      PRANTL=0.71849 - TAS * 1.275E -4
      GRASOF=32.2 * TDEL *(CL**3.)/((VAIR**2.)*(TAS+459.7))
      KASP=12.*THKAIR*0.42*(PRANTL*GRASOF)**0.219
      RETURN
      END

      SUBROUTINE SOLVLE(A,N,NP,INDX,VV,B)
C   GIVEN AN NXN MATRIX A, WITH PHYSICAL DIMENSION NP, THIS ROUTINE
C   REPLACE IT BY THE LU DECOMPOSITION OF A ROWWISE PERMUTATION OF
C   ITSELF. INDX IS AN OUTPUT VECTOR WHICH RECORD THE ROW PERMUTATION
C   EFFECTED BY THE PARTIAL PIVOTING; VV IS VECTOR OF SCALING FACTORS.
C
C   THIS ROUTINE IS USED TO SOLVE THE LINEAR SET OF EQUATIONS :
C   [A][X]=[B]
C
      DIMENSION A(NP,NP),INDX(N),VV(N),B(N)
C
C   FORM IMPLICIT SCALING VECTOR VV
C
      DO 12 I=1,N
        AAMAX = 0.0
        DO 11 J=1,N
         IF(ABS(A(I,J)).GT.AAMAX) AAMAX=ABS(A(I,J))
   11   CONTINUE
        IF(AAMAX.EQ.0.) THEN
          WRITE(7,100) I
100     FORMAT(1X,'ERROR:SINGULAR MATRIX - ZERO ROW : ROW',I5)
          RETURN
        END IF
       VV(I) = 1.0/AAMAX
   12 CONTINUE
C
C   CROUT METHOD: LOOP OVER COLUMNS
C
      DO 19 J=1,N
        DO 14 I=1,J-1
          SUM = A(I,J)
          DO 13 K=1,I-1
            SUM = SUM - A(I,K)*A(K,J)
   13     CONTINUE
        A(I,J) = SUM
   14   CONTINUE
C
C   PIVOT IMPLEMENTATION
C
        AAMAX = 0.0D0
        DO 16 I=J,N
          SUM = A(I,J)
          DO 15 K=1,J-1
            SUM = SUM - A(I,K)*A(K,J)
   15     CONTINUE
          A(I,J) = SUM
          DUM = VV(I)*ABS(SUM)
          IF(DUM.GE.AAMAX) THEN
            IMAX = I
            AAMAX = DUM
          ENDIF
   16   CONTINUE

        IF(J.NE.IMAX) THEN
          DO 17 K=1,N
            DUM = A(IMAX,K)
            A(IMAX,K) = A(J,K)
            A(J,K) = DUM
   17     CONTINUE
        VV(IMAX) = VV(J)
      ENDIF
      INDX(J) = IMAX
```

```
      IF(A(J,J).EQ.0.0) THEN
        WRITE(7,110) J
110     FORMAT(1X,'ERROR: SINGULAR MATRIX - ZERO " DIAG " : ROW',I5)
        RETURN
      END IF
      IF(J.NE.N) THEN
        DUM = 1.0/A(J,J)
        DO 18 I=J+1,N
          A(I,J) = A(I,J)*DUM
   18   CONTINUE
      END IF
   19 CONTINUE
C
C   FORWARD SUBSTITUTION
C
      II = 0
      DO 22 I=1,N
        LL = INDX(I)
        SUM = B(LL)
        B(LL) = B(I)
        IF(II.NE.0) THEN
        DO 21 J=II,I-1
          SUM = SUM - A(I,J)*B(J)
   21     CONTINUE
        ELSE IF(SUM.NE.0.0) THEN
         II = I
        END IF
        B(I) = SUM
   22 CONTINUE
C
C   BACKWARD SUBSTITUTION
C
      DO 24 I=N,1,-1
        SUM = B(I)
        IF(I.LT.N) THEN
          DO 23 J=I+1,N
          SUM = SUM - A(I,J)*B(J)
   23     CONTINUE
        END IF
        B(I) = SUM/A(I,I)
   24 CONTINUE
      RETURN
      END
```

```
      PROGRAM UHDSH
C THIS IS A MAIN PROGRAM FOR HEAT LOSS ANALYSIS OF SHALLOW TRENCH
C UNDERGROUND HEAT DISTRIBUTION SYSTEMS WITH HORIZONTAL PIPE SUPPORTS
C BASE ON THE FINITE ELEMENT METHOD USING THREE - NODE LINEAR
C TRIANGULAR ELEMENTS.
C SUBROUTINES CALLED: PIPEH, TGO,SOILK,INSULK,TGXX,SOLVLE,PIPEHLH,TWOPIP.
C     INPUT DATA FILES: DATAH1 AND DATAH2
C     X(I): THE X-COORDINATE OF NODAL POINT I,IN FT
C     Y(I): THE Y-COORDINATE OF NODAL POINT I,IN FT
C     (NODE(M,I),I=1,3): THREE NODAL POINTS OF ELEMENT M
C     M      ELEMENT INDEX
C     NE     TOTAL NUMBER OF ELEMENTS
C     NN     TOTAL NUMBER OF NODAL POINTS
C     MZ     TOTAL NUMBER OF KNOWN NODAL TEMPERATURES
C     C      THERMAL CONDUCTIVITY, BTU-IN/HR/FT**2/DEG F
C     L      THICKNESS OF THE ELEMENT, FT
C     T(I): THE TEMPERATURE OF NODAL POINT I, IN DEG F
      REAL L,KK,KI,KG,KIX1,KIX2,KTCT,KASP,KS
      CHARACTER*4 TITLE(15)
      DIMENSION Q(150),T(150),X(150),Y(150),KK(150,150)
      DIMENSION AS(250),B2IZ(250),B3IZ(250),B2JZ(250),B2KZ(250),
     & B3JZ(250),B3KZ(250)
      DIMENSION CC(250),TGX(12,5),QQ(150),NODE(250,3),MAT(250)
      DIMENSION HIJ(250),HJK(250),HKI(250),TIJ(250),TJK(250),
     & TKI(250),HHIJ(250),HHJK(250),HHKI(250),IXCB(250)
      DIMENSION CK(150,150),DQ(150),XT(150),INDX(150),VV(150)
      COMMON/PP/TP1,TP2,KI,KG,D1,D2,TH1,TH2,DP1,DP2,S1,S2,TG,
     & WW,HY,MONTH,KS,ST1,ST2
      COMMON /EK/D1P,D2P,A,B,THK1,THK2
      COMMON /ST/AO,BO,DIFF
      PI=4.*ATAN(1.)
      OPEN (8,FILE='DATAH1')
      OPEN (7,FILE='OTFILEH',STATUS='NEW',FORM='FORMATTED')
      OPEN (9,FILE='DATAH2')
C  READ IN THE TITLE OF THE PROBLEM TO BE ANALYZED
      READ (8,2,ERR=2000) TITLE
2     FORMAT(15A4)
      WRITE (7,3) TITLE
3     FORMAT(1X,15A4)
C  READ TOTAL NUMBER OF NODAL POINTS, TOTAL NUMBER OF TRIANGULAR
C  ELEMENTS, TOTAL NUMBER OF KNOWN NODAL TEMPERATURES, AND THE
C  FIRST ELEMENT INDEX OF PIPE INSULATION
      READ (8,*) NN,NE,MZ,MINS
C  READING IN THE INDEX FOR THE TYPE OF UNDERGROUND SYSTEMS :
C          ITREN = 1 FOR SHALLOW TRENCH
C                = 0 FOR LOOSE-FILL INSULATION
      READ (8,*) ITREN
C  SET THE UNIT NUMBER OF THE PRINTER
      MO=7
C  READ MONTH OF INTEREST AND THE INDEX FOR FINITE ELEMENT GRID DATA
C  TO BE PRINTED OUT : ICALB = 1  PRINT OUT NODAL COORDINATES
C                            = 0  NO PRINT OUT
      READ (8,*) MONTH,ICALB
      IF(ITREN.EQ.1) THEN
C   READ THE THERMAL CONDUCTIVITY (IN BTU-IN./H-FT**2 - DEG F) AND
C   THICKNESS (IN INCHES) OF CONCRETE WALL, AND THE THICKNESS OF
C   CONCRETE TRENCH COVER (IN FT.) AND THE THICKNESS OF CONCRETE
C   FLOOR (IN FT. ) FOR SHALLOW TRENCH SYSTEMS.
        READ (8,*) KTCT,TRTK,D,F
C   READ THE ESTIMATED AVERAGE TEMPERATURE OF AIR INSIDE THE SHALLOW
C   TRENCH, IN DEG F, AND THE TEMPERATURE DIFFERENCE BETWEEN THE
C   EFFECTIVE PIPE SURFACE TEMPERATURE AND THE INNER SURFACE
C   TEMPERATURE OF THE TRENCH, IN DEG F
        READ (8,*) TAS,TDEL
      ELSE
C  READING IN THERMAL CONDUCTIVITY AND THICKNESS (IN INCHES) OF SOIL
C  IN INNER EARTH REGION, AND THE DEPTH OF EARTH COVER (IN FT.).
        READ (8,*) KTCT,TRTK,D
C  READ IN THE THERMAL CONDUCTIVITY OF POURED-IN INSULATION MATERIAL
C  SURROUNDING THE PIPES FOR LOOSE-FILL INSULATION SYSTEMS
        READ (8,*) KASP
      END IF
C  READING IN INPUT DATA FOR CALCULATIONS OF PIPE HEAT LOSS AND
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C  GENERATION OF THE COORDINATES OF NODAL POINTS
      CALL PIPEH(X,Y,ITREN,TRTK,D,F,INXK)
      CALL TWOPIP(1,ITREN)
      CALL EQUIK(TAS,TDEL,KASP)
      IF(ICALB.EQ.1) THEN
      WRITE(7,5)
5     FORMAT('  X(M),M=1,NN')
      WRITE(7,7) (X(I),I=1,NN)
7     FORMAT(10F7.2)
      WRITE(7,10)
10    FORMAT('  Y(M),M=1,NN')
      WRITE(7,7) (Y(I),I=1,NN)
      END IF
C  CALCULATIONS OF UNDISTURBED EARTH TEMPERATURES AT VARIOUS DEPTHS
      CALL TGO(TGX,PI,Y)
C  INITIALIZATION OF THE INDEX OF CONVECTION BOUNDARY FOR ELEMENT N
      DO 12 N=1,NE
12    IXCB(N)=O
C  PERFORM ITERATIONS TO ACCOUNT FOR THE TEMPERATURE EFFECTS ON SOIL
C  AND INSULATION THERMAL CONDUCTIVITIES
        DO 24 I=1,NN
24          T(I)=TG
       DO 26 I=1,NE
          HIJ(I)=0.
          HJK(I)=0.
          HKI(I)=0.
          TIJ(I)=0.
          TJK(I)=0.
          TKI(I)=0.
          HHIJ(I)=0.
          HHJK(I)=0.
          HHKI(I)=0.
26       CONTINUE
C     READING IN THE ELEMENT NUMBER AND ITS NODAL POINTS AND THE
C     MATERIAL TYPE, WHICH INCLUDES
C        MAT(J) = 1  CONCRETE TRENCH
C               = 2  PIPE INSULATION
C               = 3  AIR SPACE SURROUNDING THE PIPES IN TRENCH
C               = 4  SOIL SURROUNDING THE TRENCH
C               = 5  STEEL PIPE SUPPORT OR BASE PLATE
      DO 30 I=1,NE
        READ(9,*) J,(NODE(J,K),K=1,3),MAT(J)
        IF (MAT(J).EQ.1) CC(J)=KTCT/12.
        IF (MAT(J).EQ.2) CC(J)=KI/12.
        IF (MAT(J).EQ.3) CC(J)=KASP/12.
        IF (MAT(J).EQ.4) CC(J)=KG/12.
        IF (MAT(J).EQ.5) CC(J)=KS/12.
30    CONTINUE
C   READ IN TOTAL NUMBER OF ELEMENTS HAVING BOUNDARY SEGMENTS SUBJECT
C   TO CONVECTIVE HEAT TRANSFER
      READ (9,*) NECB
C   READ IN ELEMENT NUMBER, CONVECTIVE HEAT TRANSFER COEFFICIENTS,
C   AND AMBIENT TEMPERATURES FOR THREE BOUNDARY SEGMENTS
      DO 35 I=1,NECB
        READ (9,*) M,HIJ(M),HJK(M),HKI(M),TIJ(M),TJK(M),TKI(M)
        IXCB(M)=1
35    CONTINUE
      ITER=1
38    DO 40 I=1,NN
      DO 40 J=1,NN
         Q(I)=0.
         KK(I,J)=0.
         QQ(I)=0.
         CK(I,J)=0.
         DQ(I)=0.
         VV(I)=1.0
         INDX(I)=1
40    CONTINUE
      L=1.
      DO 180 M=1,NE
        I=NODE(M,1)
        J=NODE(M,2)
        K=NODE(M,3)
```

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      IF (MAT(M).EQ.3) CC(M)=KASP/12.
      C=CC(M)
      IF ((INXK.EQ.0).OR.(ITER.EQ.1)) GO TO 60
C  DETERMINE SOIL AND INSULATION THERMAL CONDUCTIVITIES BASED ON THE
C  MEAN TEMPERATURES
      TM=(T(I)+T(J)+T(K))/3.
      IF(MAT(M).EQ.2)  CALL INSULK(TM,C)
      IF(MAT(M).EQ.4)  CALL SOILK(TM,KG,C)
      CC(M)=C
60    XI=X(I)
      XJ=X(J)
      XK=X(K)
      YI=Y(I)
      YJ=Y(J)
      YK=Y(K)
      CXX=C
      CXY=0.
      CYX=0.
      CYY=C
      B2I=YJ-YK
      B3I=XK-XJ
      B2J=YK-YI
      B3J=XI-XK
      B2K=YI-YJ
      B3K=XJ-XI
C   CALCULATE THE ELEMENT AREA
      SA=0.5*(XJ*B2J+XI*B2I+XK*B2K)
      SA=ABS(SA)
      A2=SA*2.
      AS(M)=A2
      B2I=B2I/A2
      B3I=B3I/A2
      B2J=B2J/A2
      B3J=B3J/A2
      B2K=B2K/A2
      B3K=B3K/A2
      B2IZ(M)=B2I
      B3IZ(M)=B3I
      B2JZ(M)=B2J
      B3JZ(M)=B3J
      B2KZ(M)=B2K
      B3KZ(M)=B3K
      BII=SA*L*(B2I*B2I*CXX+B2I*B3I*CXY+B3I*B2I*CYX+B3I*B3I*CYY)
      BIJ=SA*L*(B2I*B2J*CXX+B2I*B3J*CXY+B3I*B2J*CYX+B3I*B3J*CYY)
      BIK=SA*L*(B2I*B2K*CXX+B2I*B3K*CXY+B3I*B2K*CYX+B3I*B3K*CYY)
      BJI=SA*L*(B2J*B2I*CXX+B2J*B3I*CXY+B3J*B2I*CYX+B3J*B3I*CYY)
      BJJ=SA*L*(B2J*B2J*CXX+B2J*B3J*CXY+B3J*B2J*CYX+B3J*B3J*CYY)
      BJK=SA*L*(B2J*B2K*CXX+B2J*B3K*CXY+B3J*B2K*CYX+B3J*B3K*CYY)
      BKI=SA*L*(B2K*B2I*CXX+B2K*B3I*CXY+B3K*B2I*CYX+B3K*B3I*CYY)
      BKJ=SA*L*(B2K*B2J*CXX+B2K*B3J*CXY+B3K*B2J*CYX+B3K*B3J*CYY)
      BKK=SA*L*(B2K*B2K*CXX+B2K*B3K*CXY+B3K*B2K*CYX+B3K*B3K*CYY)
      KK(I,I)=KK(I,I)+BII
      KK(I,J)=KK(I,J)+BIJ
      KK(I,K)=KK(I,K)+BIK
      KK(J,I)=KK(J,I)+BJI
      KK(J,J)=KK(J,J)+BJJ
      KK(J,K)=KK(J,K)+BJK
      KK(K,I)=KK(K,I)+BKI
      KK(K,J)=KK(K,J)+BKJ
      KK(K,K)=KK(K,K)+BKK
      IF(IXCB(M).EQ.0) GO TO 130
C   ADDITION OF CONVECTION TERMS TO THE ELEMENT MATRIX TO ACCOUNT
C   FOR CONVECTION ON BOUNDARY
C   READING IN CONVECTIVE HEAT TRANSFER COEFFICIENTS AND AMBIENT
C   TEMPERATURES FOR THREE BOUNDARY SEGMENTS
      HHIJ(M)=HIJ(M)*L*SQRT((X(I)-X(J))**2+(Y(I)-Y(J))**2)/6.
      HHJK(M)=HJK(M)*L*SQRT((X(J)-X(K))**2+(Y(J)-Y(K))**2)/6.
      HHKI(M)=HKI(M)*L*SQRT((X(K)-X(I))**2+(Y(K)-Y(I))**2)/6.
      KK(I,I)=HHIJ(M)*2.+HHKI(M)*2.+KK(I,I)
      KK(I,J)=HHIJ(M)+KK(I,J)
      KK(I,K)=HHKI(M)+KK(I,K)
      KK(J,I)=HHIJ(M)+KK(J,I)
      KK(J,J)=HHIJ(M)*2+HHJK(M)*2.+KK(J,J)
```

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      KK(J,K)=HHJK(M)+KK(J,K)
      KK(K,I)=HHKI(M)+KK(K,I)
      KK(K,J)=HHJK(M)+KK(K,J)
      KK(K,K)=HHJK(M)*2.+HHKI(M)*2.+KK(K,K)
      HHIJ(M)=TIJ(M)*3.*HHIJ(M)
      HHJK(M)=TJK(M)*3.*HHJK(M)
      HHKI(M)=TKI(M)*3.*HHKI(M)
130   Q(I)=Q(I)+HHIJ(M)+HHKI(M)
      Q(J)=Q(J)+HHIJ(M)+HHJK(M)
      Q(K)=Q(K)+HHJK(M)+HHKI(M)
180   CONTINUE
C   DETERMINE IF FINITE ELEMENT GRID DATA ARE TO BE PRINTED OUT
      IF ((ICALB.EQ.1).AND.(ITER.EQ. 3 )) THEN
      WRITE(7,185)
185   FORMAT('      M      I      J      K     MAT.     C')
      DO 190 I=1,NE
      WRITE(7,187) I,(NODE(I,J),J=1,3),MAT(I),CC(I)
187   FORMAT(1X,5I6,F10.4)
190   CONTINUE
      END IF
C   DETERMINE OUTER SURFACE TEMPERATURES OF UNDERGROUND PIPES
      DO 200 I=1,8
        T(I)=TP1
        II=I+8
        T(II)=TP2
200   CONTINUE
      DO 202 I=1,2
         I16=I+16
         I18=I+18
         T(I16)=TP1
         T(I18)=TP2
202    CONTINUE
C   DETERMINE OUTER BOUNDARY TEMPERATURES OF EARTH REGION
      CALL TGXX(T,TGX,MONTH)
      MZ1=MZ+1
      DO 260 I=MZ1,NN
        SUM=0.
        DO 250 J=1,MZ
250       SUM=SUM+KK(I,J)*T(J)
        QQ(I)=Q(I)-SUM
260   CONTINUE
      IF(ICALB.EQ.1) THEN
         WRITE(7,280)
280      FORMAT(6X,'QQ    ARRAY')
         WRITE(7,285) (QQ(I),I=1,NN)
285      FORMAT (6E12.5)
      END IF
C  RENAMING OF MATRICES
      MN=NN-MZ
      DO 300 I=1,MN
         K=MZ+I
        DO 290 J=1,MN
            KL=MZ+J
290         CK(I,J)=KK(K,KL)
            XT(I)=T(K)
            DQ(I)=QQ(K)
300      CONTINUE
C  SOLUTION OF SIMULTANEOUS EQUATIONS
C  SET PHYSICAL DIMENSION OF MATRIX A
       NP=150
      CALL SOLVLE(CK,MN,NP,INDX,VV,DQ)
      DO 310 I=1,MN
           K=MZ+I
           T(K)=DQ(I)
310    CONTINUE
C  CALCULATE THE AVERAGE SURFACE TEMPERATURE OF INSULATED PIPES
       SU1=0.
       SU2=0.
       DO 312 I=1,8
         L1=I+73
         L2=I+81
         SU1=SU1+T(L1)
         SU2=SU2+T(L2)
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312     CONTINUE
        TSM1=SU1/8.
        TSM2=SU2/8.
C    DETERMINE THE EFFECTIVE SURFACE TEMPERATURE OF INSULATED
C    PIPES, IN DEG F
        DIP1=D1P+2.*THK1
        DIP2=D2P+2.*THK2
        TEFPS=(DIP1*TSM1+DIP2*TSM2)/(DIP1+DIP2)
C   CALCULATE THE INNER SURFACE TEMPERATURE OF THE TRENCH
        SU3=0.
        DO 314 I=1,14
          L3=I+40
314     SU3=SU3+T(L3)
        TEFTS=SU3/14.
C   DETERMINE THE TEMPERATURE DIFFERENCE BETWEEN THE EFFECTIVE
C   SURFACE TEMPERATURE OF INSULATED PIPES AND THE INNER SURFACE
C   TEMPERATURE OF THE TRENCH, IN DEG F
        TDEL=ABS(TEFPS-TEFTS)
        TAS=(TEFPS+TEFTS)/2.
C   DETERMINE THE EFFECTIVE THERMAL CONDUCTIVITY OF AIR SPACE
        CALL EQUIK(TAS,TDEL,KASP)
        WRITE (7,316) KASP
316     FORMAT('  KASP=',F10.4,2X,'(BTU-IN./H-FT**2-DEG F)')
330     FORMAT('  TEMPERATURE ARRAY : T(I), I=1,NN ')
C   CALCULATE THE MEAN VALUES OF INSULATION THERMAL CONDUCTIVITY FOR
C   PIPES 1 AND 2
350     SKI1=0.
        SKI2=0.
        DO 400 LN=1,16
           LM=MINS+LN-1
           LL=LM+16
           SKI1=SKI1+CC(LM)
           SKI2=SKI2+CC(LL)
400     CONTINUE
        KIX1=SKI1/16.
        KIX2=SKI2/16.
        R1=D1/24.
        R2=D2/24.
        TH1X=TH1/12.
        TH2X=TH2/12.
        IF(ICALB .EQ. 0) THEN
          MO=11
          IF(ITER .EQ. 3 ) MO=7
        END IF
C   CALCULATIONS OF THE HEAT LOSSES FROM THE UNDERGROUND PIPES
        CALL  PIPEHLH(T,R1,R2,TH1X,TH2X,KIX1,KIX2,KS,ST1,ST2,MO,QTX)
        HLOSS=QTX
        IF (ITER.EQ.1) HLOSX=0.
C   DETERMINE IF PIPE HEAT LOSS VALUE HAS CONVERGED OR CONTINUE
C   ITERATIONS IF REQUIRED
        DELQT=ABS(HLOSS-HLOSX)/HLOSS
        IF (DELQT.LE.0.005) GO TO 2010
        ITER=ITER+1
        HLOSX=HLOSS
        GO TO 38
2000    WRITE (7,2005)
2010    IF (ICALB.EQ.1) THEN
        WRITE(7,330)
        WRITE(7,285) (T(I),I=1,NN)
        END IF
2005    FORMAT (1X,'THERE ARE SOME ERRORS IN INPUT DATA')
        STOP
        END

        SUBROUTINE TGO(TGX,PI,Y)
C    THIS SUBROUTINE CALCULATES THE UNDISTURBED EARTH TEMPERATURES
C    AT VARIOUS DEPTHS
        DIMENSION TGX(12,5),Y(150)
C       READING IN THE ANUAL AVERAGE TEMPERATURE AND AMPLITUDE OF THE
C       MONTHLY NORMAL TEMPERATURE CYCLE OF THE SITE, IN DEG F, AND
C       THERMAL DIFFUSIVITY OF SOIL, IN FT**2/H.
        READ (8,*) AO,BO,DIFF
        W=2.*PI/12.
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      WZ=2.*PI/(8760*DIFF*2)
      ZZ=SQRT(WZ)
      DO 1 I=1,12
      DO 1 J=1,5
      Z=ZZ*Y(33-J)
1     TGX(I,J)=AO+BO*EXP(-Z)*SIN(W*(I-3)-Z)
      RETURN
      END

      SUBROUTINE TGXX(T,TGX,MONTH)
C THIS SUBROUTINE PROVIDES OUTER BOUNDARY TEMPERATURES OF EARTH REGION
      DIMENSION T(150),TGX(12,5)
      T(32)=TGX(MONTH,1)
      DO 1 I=1,8
         II=I+32
1        T(II)=T(32)
      DO 5 I=2,5
         I19=I+19
         JI=33-I
         T(I19)=TGX(MONTH,I)
         T(JI)=TGX(MONTH,I)
5     CONTINUE
      DO 10 I=1,3
         I24=I+24
10     T(I24)=TGX(MONTH,5)
      RETURN
      END

      SUBROUTINE INSULK(TM,C)
C  THIS SUBROUTINE DETERMINES THE THERMAL CONDUCTIVITY OF PIPE
C  INSULATION (CALCIUM SILICATE) AS A FUNCTION OF THE MEAN
C  TEMPERATURE.
      REAL KN(16),KINS
      DIMENSION TN(16)
      DATA KN /0.375,0.40,0.42,0.45,0.48,0.50,0.53,0.555,0.58,0.61,
     & 0.63,0.66,0.68,0.74,0.82,0.90/
      DO 5 J=1,16
      IF(J .LE. 13) THEN
         TN(J)=100.+(J-1)*50.
      ELSE
         TN(J)=700.+(J-13)*100.
      END IF
5     CONTINUE
      IF(TM .GT. TN(1)) GO TO 10
      KINS=KN(1)
      GO TO 100
10    IF(TM .LT. TN(16)) GO TO 20
      KINS=KN(16)
      GO TO 100
20    DO 50 I=1,15
      T1=TM-TN(I)
      IF(T1 .NE. 0.) GO TO 30
      KINS=KN(I)
      GO TO 100
30    T2=TN(I+1)-TM
      IF(T2 .NE. 0.) GO TO 40
      KINS=KN(I+1)
      GO TO 100
40    P=T1*T2
      IF(P .LT. 0.) GO TO 50
      KINS=KN(I)+T1*(KN(I+1)-KN(I))/(TN(I+1)-TN(I))
      GO TO 100
50    CONTINUE
100   C=KINS/12.
      RETURN
      END

      SUBROUTINE  SOILK(TM,KG,C)
C THIS ROUTINE DETERMINES THE THERMAL CONDUCTIVITY OF SOIL AS A
C FUNCTION OF MEAN TEMPERATURES.
      REAL K(14),KG
      DIMENSION TX(14)
      DATA K/1.1,1.1,1.1,1.0,0.4,0.31,0.25,0.19,0.15,0.11,0.09,0.07,
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```
     & 0.05,0.05/
      DO 1 I=1,14
1        TX(I)=50.+(I-1)*25.
      IF(TM.GT.TX(1)) GO TO 5
      ZK=1.1
      GO TO 50
5     IF(TM.LT.TX(14)) GO TO 10
      ZK=0.05
      GO TO 50
10    DO 25 I=1,13
      T1=TM-TX(I)
      IF(T1.NE.0) GO TO 15
      ZK=K(I)
      GO TO 50
15    CONTINUE
      T2=TM-TX(I+1)
      IF(T2.NE.0.) GO TO 20
      ZK=K(I+1)
      GO TO 50
20    CONTINUE
      P=T1*T2
      IF(P.GT.0) GO TO 25
      ZK=K(I+1)+T2*(K(I+1)-K(I))/25.
      GO TO 50
25    CONTINUE
50    C=ZK*KG/(1.1*12.)
      RETURN
      END

      SUBROUTINE PIPEHLH(T,R1,R2,TH1,TH2,ZKS1,ZKS2,ZKS,ST1,ST2,MO,QT)
C  THIS SUBROUTINE CALCULATES THE AVERAGE TEMPERATURE DROPS ACROSS THE
C  PIPE INSULATIONS AND THE RATES OF HEAT LOSS FROM THE UNDERGROUND
C  PIPES IN TRENCH SYSTEM
      DIMENSION T(150)
      PI=4.*ATAN(1.)
C  HEAT LOSSES THROUGH PIPE SUPPORTS
      RA1=ST1/(2.*R1)
      RA2=ST2/(2.*R2)
      OMEG1=2.*ASIN(RA1)
      OMEG2=2.*ASIN(RA2)
      DTS1=(T(17)+T(6)+T(18))-(T(106)+T(79)+T(107))
      DTS2=(T(19)+T(10)+T(20))-(T(108)+T(83)+T(109))
      ZKST=ZKS/12.
      Q1S=ZKST*OMEG1*DTS1/LOG((R1+TH1)/R1)
      Q2S=ZKST*OMEG2*DTS2/LOG((R2+TH2)/R2)
C  HEAT LOSSES THROUGH PIPE INSULATION
      SUM1=0.
      SUM2=0.
      N1=7
      DO 1 I=1,8
         K1=I
         K3=I+73
         IF (I .NE. 6) THEN
           SUM1=SUM1+T(K1)-T(K3)
         END IF
1     CONTINUE
      DO 2 I=1,8
         K2=I+8
         K4=I+81
         IF (I .NE. 2) THEN
           SUM2=SUM2+T(K2)-T(K4)
         END IF
2     CONTINUE
      T1=SUM1/N1
      T2=SUM2/N1
      ZKIS1=ZKS1*12.
      ZKIS2=ZKS2*12.
      Q1A=ZKS1*1.5*PI*T1/LOG((R1+TH1)/R1)
      Q2A=ZKS2*1.5*PI*T2/LOG((R2+TH2)/R2)
      DTI1=(T(5)+T(17)+T(18)+T(7))-(T(78)+T(106)+T(107)+T(80))
      DTI2=(T(9)+T(19)+T(20)+T(11))-(T(82)+T(108)+T(109)+T(84))
      Q1B=ZKS1*(0.5*PI-OMEG1)*DTI1/LOG((R1+TH1)/R1)
      Q2B=ZKS2*(0.5*PI-OMEG2)*DTI2/LOG((R2+TH2)/R2)
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C  COMBINED PIPE HEAT LOSSES
      Q1=Q1A+Q1B+Q1S
      Q2=Q2A+Q2B+Q2S
      QT=Q1+Q2
      IF(MO .EQ. 11) GO TO 50
      WRITE(MO,5) ZKIS1,ZKIS2
5     FORMAT(/'  AVERAGE VALUES OF PIPE INSULATION THERMAL',
     &' CONDUCTIVITY :',/,'    KI1 = ',F10.3,'    KI2 = ',F10.3,
     & '    BTU-IN/H-FT**2-DEG F ')
      WRITE(MO,10) T1,T2
10    FORMAT(/'  AVERAGE TEMPERATURE DROPS ACROSS INSULATION : ',/,
     & '    T1= ',F10.2,'    T2= ',F10.2,'  DEG F')
      WRITE(MO,20) Q1,Q2,QT
20    FORMAT(/,2X,'HEAT LOSSES FROM UNDERGROUND PIPES :'/'    Q1=',
     & F10.2, '    Q2=',F10.2,'    QT=',F10.2,'  BTU/H-FT')
50    RETURN
      END

      SUBROUTINE PIPEH(X,Y,ITREN,TRTK,D,F,INXK)
C THIS SUBROUTINE READS IN THE INPUT DATA TO BE USED FOR CALCULATIONS
C OF THE HEAT LOSSES FROM THE UNDERGROUND PIPES AND GENERATES X AND Y-
C COORDINATES OF NODAL POINTS FOR THE TWO PIPE SYSTEM.
      REAL KII,KIG,KI,KG,KS
      DIMENSION X(150),Y(150)
      COMMON /PP/TP1,TP2,KII,KIG,DI1,DI2,THI1,THI2,B1,B2,S1,S2,TG,
     & WW,HY,MONTH,KS,ST1,ST2
      COMMON /EK/D1P,D2P,A,B,THK1,THK2
C READ TEMPERATURE OF PIPE NUMBERS 1 2, IN DEG F
      READ (8,*) TP1,TP2
C READ THERMAL CONDUCTIVITY OF THERMAL INSULATION,SOIL,AND PIPE
C SUPPORT, IN BTU-IN./H-FT**2 - DEG F,AND INDEX OF THERMAL
C CONDUCTIVITY : INXK = 0  CONSTANT THERMAL CONDUCTIVITY
C                     = 1  TEMPERATURE DEPENDENT THERMAL CONDUCTIVITY
      READ (8,*) KII,KIG,KS,INXK
C READING IN THE OUTSIDE DIAMETERS OF STEEL PIPES 1 AND 2, IN INCHES
      READ (8,*) DI1,DI2
C READING IN THE THICKNESS OF THERMAL INSULATION USED FOR PIPES 1
C AND 2, RESPECTIVELY, IN INCHES
      READ (8,*) THI1,THI2
C READ THE DEPTHS FROM GROUND SURFACE TO THE CENTERS OF PIPES 1 AND
C 2, RESPECTIVELY, IN FT.
      READ (8,*) B1,B2
C   READING IN THE HORIZONTAL DISTANCES (IN FT.) FROM VERTICAL
C   CENTERLINE OF THE TRENCH TO CENTERS OF PIPES 1 AND 2,
C   RESPECTIVELY, AND THE AVERAGE EARTH TEMPERATURE, IN DEG F.
      READ (8,*) S1,S2,TG
C   READ IN THE WIDTH AND DEPTH OF EARTH REGION SURROUNDING THE
C   UNDERGROUND SYSTEM, IN FT.
      READ (8,*) WW,HY
C   READ IN THE WIDTHS AND THICKNESSES OF PIPE SUPPORTS 1 AND 2,
C   RESPECTIVELY, IN INCHES.
      READ(8,*) SW1,SW2,ST1,ST2
C   READ IN THE HEIGHT AND WIDTH OF THE WALL PLATES, IN INCHES.
      READ(8,*) PH,PW
      WRITE(7,10) TP1,TP2,KII,KIG,DI1,DI2
10    FORMAT('   TP1    TP2     KI     KG     D1     D2'/6F7.2)
      WRITE(7,20) THI1,THI2,B1,B2,S1,S2,TG
20    FORMAT('   THI1   THI2    DP1    DP2     S1     S2     TG',
     & /7F7.2)
      WRITE(7,30) WW,HY,MONTH
30    FORMAT('     WW     HY  MONTH '/2F7.2,I7)
      WRITE(7,32) SW1,SW2,ST1,ST2,PH,PW
32    FORMAT('     SW1    SW2    ST1    ST2     PH     PW',/1X,6F7.3)
C   READ IN THE INNER WIDTH AND HEIGHT OF THE TRENCH, OR THE WIDTH
C   AND HEIGHT OF THE INNER EARTH REGION FOR LOOSE-FILL INSULATION
C   SYSTEMS, IN FT.
      READ (8,*) A,B
C   CHANGE TO ENGINEERING UNITS
      D1=DI1/12.
      R1=D1*0.5
      D2=DI2/12.
      R2=D2*0.5
      D1P=DI1/12.
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```
      D2P=DI2/12.
      SW1=SW1/12.
      SW2=SW2/12.
      ST1=ST1/12.
      ST2=ST2/12.
      PH=PH/12.
      PW=PW/12.
      KI=KII/12.
      KG=KIG/12.
      IF(ITREN .EQ. 1) THEN
        W=A+2*TRTK/12
        H=B+D+F
      ELSE
        W=2*A
        H=2.*B+D
      END IF
      WRITE(7,40) W,H,D,F,A,B,WW,HY
40    FORMAT('     W      H      D      F      A      B     WW      HY'
     &,/,8F7.2)
      PI=4.*ATAN(1.)
      TH1=THI1/12.
      TH2=THI2/12.
      THK1=THI1/12.
      THK2=THI2/12.
C   DETERMINE THE X AND Y-COORDINATES OF CONCRETE TRENCH COVER,
C   AND FLOOR (NODAL POINTS 34 TO 38, 44 TO 48, AND 52 TO 54)
      DO 50 I=1,5,2
        I33=I+33
        X(I33)=W-(I-1)*W/4.
50      Y(I33)=0.
      DO 60 I=1,3,2
         I34=I+34
         X(I34)=(W+A)*0.5 - A*(I-1)*0.5
60       Y(I34)=0.
      DO 62 I=1,3
         I51=I+51
         I54=I+54
         I58=I+58
         I62=I+62
         X(I51)=0.5*(W+A)-I*A/4.
         Y(I51)=D
         X(I54)=0.
         Y(I54)=D+B*(I-1)/2.
         X(I58)=(W-A)*0.5+(I-1)*A/2.
         Y(I58)=D+B+F
         X(I62)=W
         Y(I62)=D+(3-I)*B/2.
62    CONTINUE
      DO 65 I=1,5
         I43=I+43
         X(I43)=0.5*(W-A)+(I-1)*A/4.
         Y(I43)=D+B
65     CONTINUE
         X(58)=0.
         Y(58)=D+B+F
         X(62)=W
         Y(62)=D+B+F
C   X AND Y-COORDINATES OF THE CENTERS OF THE PIPES
      XC1=W*0.5 - S1
      YC1=B1
      XC2=W*0.5 + S2
      YC2=B2
      WRITE(7,90) XC1,YC1,XC2,YC2
90    FORMAT('    XC1    YC1    XC2    YC2'/4F7.3)
C   THE X AND Y-COORDINATES OF NODAL POINTS ON INTERIOR CONCRETE
C   WALLS (NODAL POINTS 41 TO 43, 49 TO 51, 110 TO 113, AND 114
C   TO 117)
      DO 96 I=1,2
         I109=I+109
         I111=I+111
         I113=I+113
         I115=I+115
         X(I109)=(W-A)*0.5
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```
      Y(I109)=YC1-0.5*ST1+(I-1)*ST1
      X(I111)=(W+A)*0.5
      Y(I111)=YC2+0.5*ST2-(I-1)*ST2
      X(I113)=(W-A)*0.5
      Y(I113)=YC1-0.5*PH+(I-1)*PH
      X(I115)=(W+A)*0.5
      Y(I115)=YC2+0.5*PH-(I-1)*PH
96    CONTINUE
      DO 98 I=1,2
      I40=I+40
      I49=I+49
      X(I40)=(W-A)*0.5
      Y(I40)=D+(I-1)*0.5*(Y(114)-D)
      X(I49)=(W+A)*0.5
      Y(I49)=D+(Y(117)-D)*(2-I)*0.5
98    CONTINUE
      X(43)=(W-A)*0.5
      Y(43)=(D+B)-0.5*((D+B)-Y(115))
      X(49)=(W+A)*0.5
      Y(49)=(D+B)-0.5*((D+B)-Y(116))
C     THE X AND Y-COORDINATES OF OUTER BOUNDARY EARTH SURROUNDING THE
C     SHALLOW TRENCH (NODAL POINTS 21 TO 33,39,40, AND 66 TO 73)
      X(21)=-WW
      Y(21)=0.5*H
      X(31)=W+WW
      Y(31)=0.5*H
      DO 75 I=1,3
      I21=I+21
      I24=I+24
      I27=I+27
      X(I21)=-WW
      Y(I21)=H+HY*(I-1)*0.5
      X(I24)=W*(I-1)*0.5
      Y(I24)=H+HY
      X(I27)=W+WW
      Y(I27)=H+HY*(3-I)*0.5
75    CONTINUE
      DO 80 I=1,2
      I31=I+31
      I38=I+38
      I65=I+65
      I71=I+71
      X(I31)=W+WW*(3-I)*0.5
      Y(I31)=0.
      X(I38)=-WW*0.5*I
      Y(I38)=0.
      X(I65)=-WW*0.5
      Y(I65)=H*I*0.5
      X(I71)=W+WW*0.5
      Y(I71)=H*(3-I)*0.5
80    CONTINUE
      DO 85 I=1,4
      I67=I+67
      X(I67)=W*(I-1)/3.
85    Y(I67)=H+HY*0.5
C     THE X AND Y-COORDINATES OF NODAL POINTS AT THE INNER SURFACES
C     OF PIPE INSULATION AND OUTER SURFACES OF THE INSULATED PIPES
C     (NODAL POINTS 1 TO 20, 74 TO 89, AND 106 TO 109)
      DO 95 I=1,8
      THETA=2.*PI*I/8.
      I8=I+8
      I73=I+73
      I81=I+81
      X(I)=XC1+0.5*D1*SIN(THETA)
      Y(I)=YC1+0.5*D1*COS(THETA)
      X(I8)=XC2+0.5*D2*SIN(THETA)
      Y(I8)=YC2+0.5*D2*COS(THETA)
      X(I73)=XC1+(TH1+0.5*D1)*SIN(THETA)
      Y(I73)=YC1+(JH1+0.5*D1)*COS(THETA)
      X(I81)=XC2+(TH2+0.5*D2)*SIN(THETA)
      Y(I81)=YC2+(TH2+0.5*D2)*COS(THETA)
95    CONTINUE
      BETA=3.*PI/8.
```

```
      X(17)=XC1-0.5*(D1-ST1/TAN(BETA))
      Y(17)=YC1-ST1*0.5
      X(18)=X(17)
      Y(18)=YC1+ST1*0.5
      X(19)=XC2+0.5*(D2-ST2/TAN(BETA))
      Y(19)=YC2+ST2*0.5
      X(20)=X(19)
      Y(20)=YC2-ST2*0.5
      X(106)=XC1-TH1-0.5*(D1-ST1/TAN(BETA))
      Y(106)=YC1-ST1*0.5
      X(107)=X(106)
      Y(107)=YC1+ST1*0.5
      X(108)=XC2+TH2+0.5*(D2-ST2/TAN(BETA))
      Y(108)=YC2+ST2*0.5
      X(109)=X(108)
      Y(109)=YC2-ST2*0.5
C   THE X AND Y-COORDINATES OF NODAL POINTS IN AIR SPACE SURROUNDING
C   THE PIPES INSIDE THE TRENCH (NODAL POINTS 90 TO 105)
        YUP=0.5*(Y(77)-Y(53))
        YUPR=0.5*(Y(85)-Y(53))
        IF (YUPR.LT.YUP) YUP=YUPR
        XLT=0.5*(X(79)-X(43))
        XRT=0.5*(X(49)-X(83))
        YLO=0.5*(Y(46)-Y(81))
        YLOW=0.5*(Y(46)-Y(89))
        IF (YLOW .LT. YLO) YLO=YLOW
      DO 100 I=1,3
         I89=I+89
         I96=I+96
         X(I89)=0.5*(W+A)-0.25*A*I
         Y(I89)=D+YUP
         X(I96)=0.5*(W-A)+0.25*A*I
         Y(I96)=D+B-YLO
100   CONTINUE
      DO 105 I=1,2
         I92=I+92
         I94=I+94
         I99=I+99
         I101=I+101
         X(I92)=0.5*(W-A)+XLT
         Y(I92)=D+(Y(114)-D)*0.5*I
         X(I94)=0.5*(W-A)+XLT
         Y(I94)=(D+B)-0.5*((D+B)-Y(115))*(3-I)
         X(I99)=0.5*(W+A)-XRT
         Y(I99)=(D+B)-0.5*((D+B)-Y(116))*I
         X(I101)=0.5*(W+A)-XRT
         Y(I101)=D+0.5*(Y(117)-D)*(3-I)
105   CONTINUE
      DO 120 I=1,2
         II=I+103
         X(II)=X(53)
         Y(II)=D+YUP+(B-YUP-YLO)*I/3.
120   CONTINUE
C  THE X AND Y-COORDINATES OF NODAL POINTS IN STEEL WALL PLATES
C  (NODAL POINTS 118 TO 121)
       X(118)=(W-A)*0.5-PW
       Y(118)=Y(114)
       X(119)=(W-A)*0.5-PW
       Y(119)=Y(115)
       X(120)=(W+A)*0.5+PW
       Y(120)=Y(116)
       X(121)=(W+A)*0.5+PW
       Y(121)=Y(117)
       RETURN
       END

      SUBROUTINE TWOPIP(IREPT,ITREN)
C  THIS SUBROUTINE DETERMINES THE HEAT LOSSES FROM TWO PIPES TO THE
C  UNDERGROUND SURROUNDING THE HEAT DISTRIBUTION SYSTEM.
      REAL KII,KIG,KS
      COMMON /PP/T1,T2,KII,KIG,DI1,DI2,THI1,THI2,B1,B2,S1,S2,TG,
     & WW,HY,MONTH,KS,ST1,ST2
      PI=4.*ATAN(1.)
```

```
      X1=2.*PI
      R1=DI1/24.
      R2=DI2/24.
      TH1X=THI1/12.
      TH2=THI2/12.
      ZK1=KII/12.
      ZK2=ZK1
      D1=B1
      D2=B2
      ZKS=KIG/12.
      DO 10 I=1,IREPT
2     TH1=TH1X+0.1*(I-1)
      TH2=TH1
      S=S1+S2
      A=R1+R2+TH1+TH2+0.05
      THI1=TH1*12.
      IF(ITREN.EQ.1) A=S
      C1=X1*ZK1/LOG((R1+TH1)/R1)
      C2=X1*ZK2/LOG((R2+TH2)/R2)
      P11=1.+C1/(X1*ZKS)*LOG((2*D1)/(R1+TH1))
      P12=C2/(X1*ZKS)*LOG((A*A+(D1+D2)**2)/(A*A+(D1-D2)**2))*0.5
      P21=C1/(X1*ZKS)*LOG((A*A+(D1+D2)**2)/(A*A+(D1-D2)**2))*0.5
      P22=1.+C2/(X1*ZKS)*LOG((2*D2)/(R2+TH2))
      DEL=P12*P21-P11*P22
      ZKP1=C1*(P12-P22)/DEL
      ZKP2=C2*(P21-P11)/DEL
      TP1=(P12*T2-P22*T1)/(P12-P22)
      TP2=(P21*T1-P11*T2)/(P21-P11)
      Q1=ZKP1*(TP1-TG)
      Q2=ZKP2*(TP2-TG)
      QT=Q1+Q2
      TAVG=(T1+T2)*0.5
      ZK=QT/(TAVG-TG)
      WRITE(7,6) DI1,DI2,S1,S2,THI1,KII,KIG,T1,T2
6     FORMAT('   DI1   DI2    S1    S2  THI1   KII   KIG   TP1   TP2',
     &/,7F6.2,1X,2F6.0)
      WRITE(7,8) Q1,Q2,QT,ZK
8     FORMAT('    Q1     Q2     QT        KP'/,3F7.2,2X,F6.3/)
10    CONTINUE
      RETURN
      END

      SUBROUTINE EQUIK(TAS,TDEL,KASP)
C   THIS ROUTINE CALCULATES EQUIVALENT THERMAL CONDUCTIVITY OF AIR
C   SPACE SURROUNDING THE PIPES IN A SHALLOW TRENCH
      REAL KASP
      COMMON /EK/D1P,D2P,A,B,THK1,THK2
      PI=4.*ATAN(1.)
C   CALCULATE THERMAL CONDUCTIVITY, IN BTU-FT/H-FT**2-DEG F, AND
C   KINEMATIC VISCOSITY, IN FT**2/S, OF AIR
      THKAIR=0.01319 + TAS*2.5E -5
      VAIR=1.2624E -4 + TAS*5.4E -7
C   CALCULATE THE EFFECTIVE DIAMETERS OF THE RECTANGULAR TRENCH
C   AND THE INSULATED PIPES, IN FT, AND THE CHARACTERISTIC LENGTH
C   OF AIR SPACE, IN FT
      DEFTRN=2.0 * (A+B)/PI
      DEFPIP=(D1P+2.*THK1)+(D2P+2.*THK2)
      CL=DEFTRN - DEFPIP
C   CALCULATE THE PRANDTL NUMBER OF AIR , AND GRASHOF NUMBER AND
C   EQUIVALENT THERMAL CONDUCTIVITY, IN BTU-IN/H-FT**2-DEG F, OF
C   AIR SPACE
      PRANTL=0.71849 - TAS * 1.275E -4
      GRASOF=32.2 * TDEL *(CL**3.)/((VAIR**2.)*(TAS+459.7))
      KASP=12.*THKAIR*0.42*(PRANTL*GRASOF)**0.219
      RETURN
      END

      SUBROUTINE SOLVLE(A,N,NP,INDX,VV,B)
C   GIVEN AN NXN MATRIX A, WITH PHYSICAL DIMENSION NP, THIS ROUTINE
C   REPLACE IT BY THE LU DECOMPOSITION OF A ROWWISE PERMUTATION OF
C   ITSELF. INDX IS AN OUTPUT VECTOR WHICH RECORD THE ROW PERMUTATION
C   EFFECTED BY THE PARTIAL PIVOTING; VV IS VECTOR OF SCALING FACTORS.
C
```

```
C     THIS ROUTINE IS USED TO SOLVE THE LINEAR SET OF EQUATIONS :
C     [A][X]=[B]
C
        DIMENSION A(NP,NP),INDX(N),VV(N),B(N)
C
C     FORM IMPLICIT SCALING VECTOR VV
C
        DO 12 I=1,N
          AAMAX = 0.0
          DO 11 J=1,N
           IF(ABS(A(I,J)).GT.AAMAX) AAMAX=ABS(A(I,J))
   11     CONTINUE
          IF(AAMAX.EQ.0.) THEN
            WRITE(7,100) I
100       FORMAT(1X,'ERROR:SINGULAR MATRIX - ZERO ROW : ROW',I5)
            RETURN
          END IF
         VV(I) = 1.0/AAMAX
   12 CONTINUE
C
C     CROUT METHOD: LOOP OVER COLUMNS
C
        DO 19 J=1,N
          DO 14 I=1,J-1
            SUM = A(I,J)
            DO 13 K=1,I-1
              SUM = SUM - A(I,K)*A(K,J)
   13       CONTINUE
          A(I,J) = SUM
   14     CONTINUE
C
C     PIVOT IMPLEMENTATION
C
          AAMAX = 0.0D0
          DO 16 I=J,N
            SUM = A(I,J)
            DO 15 K=1,J-1
              SUM = SUM - A(I,K)*A(K,J)
   15       CONTINUE
            A(I,J) = SUM
            DUM = VV(I)*ABS(SUM)
            IF(DUM.GE.AAMAX) THEN
              IMAX = I
              AAMAX = DUM
            ENDIF
   16     CONTINUE

          IF(J.NE.IMAX) THEN
            DO 17 K=1,N
              DUM = A(IMAX,K)
              A(IMAX,K) = A(J,K)
              A(J,K) = DUM
   17       CONTINUE
          VV(IMAX) = VV(J)
        ENDIF
        INDX(J) = IMAX
        IF(A(J,J).EQ.0.0) THEN
          WRITE(7,110) J
110      FORMAT(1X,'ERROR: SINGULAR MATRIX - ZERO " DIAG " : ROW',I5)
          RETURN
        END IF
        IF(J.NE.N) THEN
          DUM = 1.0/A(J,J)
          DO 18 I=J+1,N
            A(I,J) = A(I,J)*DUM
   18     CONTINUE
        END IF
   19 CONTINUE
C
C     FORWARD SUBSTITUTION
C
        II = 0
        DO 22 I=1,N
```

```
        LL = INDX(I)
        SUM = B(LL)
        B(LL) = B(I)
        IF(II.NE.0) THEN
        DO 21 J=II,I-1
          SUM = SUM - A(I,J)*B(J)
 21       CONTINUE
        ELSE IF(SUM.NE.0.0) THEN
         II = I
        END IF
        B(I) = SUM
 22   CONTINUE
C
C    BACKWARD SUBSTITUTION
C
      DO 24 I=N,1,-1
        SUM = B(I)
        IF(I.LT.N) THEN
          DO 23 J=I+1,N
          SUM = SUM - A(I,J)*B(J)
 23       CONTINUE
        END IF
        B(I) = SUM/A(I,I)
 24   CONTINUE
      RETURN
      END
```

```
      PROGRAM UHDS
C THIS IS A MAIN PROGRAM FOR HEAT LOSS ANALYSIS OF SHALLOW TRENCH
C UNDERGROUND HEAT DISTRIBUTION SYSTEMS BASED ON THE FINITE ELEMENT
C METHOD USING THREE - NODE LINEAR TRIANGULAR ELEMENTS.
C SUBROUTINES CALLED: PIPE2, TGO,SOILK,INSULK,TGXX,SOLVLE,PIPEHL,TWOPIP.
C      INPUT DATA FILES: DATA1 AND DATA2
C      X(I): THE X-COORDINATE OF NODAL POINT I,IN FT
C      Y(I): THE Y-COORDINATE OF NODAL POINT I,IN FT
C      (NODE(M,I),I=1,3): THREE NODAL POINTS OF ELEMENT M
C      M      ELEMENT INDEX
C      NE     TOTAL NUMBER OF ELEMENTS
C      NN     TOTAL NUMBER OF NODAL POINTS
C      MZ     TOTAL NUMBER OF KNOWN NODAL TEMPERATURES
C      C      THERMAL CONDUCTIVITY, BTU-IN/HR/FT**2/DEG F
C      L      THICKNESS OF THE ELEMENT, FT
C      T(I): THE TEMPERATURE OF NODAL POINT I, IN DEG F
      REAL L,KK,KI,KG,KIX1,KIX2,KTCT,KASP
      CHARACTER*4 TITLE(15)
      DIMENSION Q(150),T(150),X(150),Y(150),KK(150,150)
      DIMENSION AS(220),B2IZ(220),B3IZ(220),B2JZ(220),B2KZ(220),
     & B3JZ(220),B3KZ(220)
      DIMENSION CC(220),TGX(12,5),QQ(150),NODE(220,3),MAT(220)
      DIMENSION HIJ(220),HJK(220),HKI(220),TIJ(220),TJK(220),
     & TKI(220),HHIJ(220),HHJK(220),HHKI(220),IXCB(220)
      DIMENSION CK(150,150),DQ(150),XT(150),INDX(150),VV(150)
      COMMON/PP/TP1,TP2,KI,KG,D1,D2,TH1,TH2,DP1,DP2,S1,S2,TG,
     & WW,HY,MONTH
      COMMON /EK/D1P,D2P,A,B,THK1,THK2
      COMMON /ST/AO,BO,DIFF
      PI=4.*ATAN(1.)
      OPEN (8,FILE='DATA1')
      OPEN (7,FILE='OUTFILE',STATUS='NEW',FORM='FORMATTED')
      OPEN (9,FILE='DATA2')
C  READ IN THE TITLE OF THE PROBLEM TO BE ANALYZED
      READ (8,2,ERR=2000) TITLE
2     FORMAT(15A4)
      WRITE (7,3) TITLE
3     FORMAT(1X,15A4)
C  READ TOTAL NUMBER OF NODAL POINTS, TOTAL NUMBER OF TRIANGULAR
C  ELEMENTS, TOTAL NUMBER OF KNOWN NODAL TEMPERATURES, AND THE
C  FIRST ELEMENT INDEX OF PIPE INSULATION
      READ (8,*) NN,NE,MZ,MINS
C  READ IN THE NUMBER OF ITERATIONS TO ACCOUNT FOR THE TEMPERATURE
C  EFFECT ON INSULATION AND SOIL THERMAL CONDUCTIVITIES AND THE INDEX
C  FOR UNDERGROUND SYSTEMS: ITREN = 1 FOR SHALLOW TRENCH
C                           ITREN = 0 FOR LOOSE-FILL INSULATION
      READ (8,*) MREPT,ITREN
C  SET THE UNIT NUMBER OF THE PRINTER
      MO=7
C  READ MONTH OF INTEREST AND THE INDEX FOR FINITE ELEMENT GRID DATA
C  TO BE PRINTED OUT : ICALB = 1  PRINT OUT NODAL COORDINATES
C                            = 0  NO PRINT OUT
      READ (8,*) MONTH,ICALB
      IF(ITREN.EQ.1) THEN
C   READ THE THERMAL CONDUCTIVITY (IN BTU-IN./H-FT**2 - DEG F) AND
C   THICKNESS (IN INCHES) OF CONCRETE WALL, AND THE THICKNESS OF
C   CONCRETE TRENCHCOVER (IN FT.) AND THE THICKNESS OF CONCRETE
C   FLOOR (IN FT.) FOR SHALLOW TRENCH SYSTEM.
        READ (8,*) KTCT,TRTK,D,F
C   READ IN THE ESTIMATED AVERAGE TEMPERATURE OF AIR INSIDE THE SHALLOW
C   TRENCH, IN DEG F,AND THE TEMPERATURE DIFFERENCE BETWEEN THE EFFECTIVE
C   INSULATED PIPE SURFACE TEMPERATURE AND THE INNER SURFACE TEMPERATURE
C   OF THE TRENCH, IN DEG F
        READ (8,*) TAS,TDEL
      ELSE
C  READING IN THERMAL CONDUCTIVITY AND THICKNESS (IN INCHES) OF SOIL
C  IN INNER EARTH REGION, AND THE DEPTH OF EARTH COVER (IN FT.).
        READ (8,*) KTCT,TRTK,D
C  READ IN THE THERMAL CONDUCTIVITY OF POURED-IN INSULATION MATERIAL
C  SURROUNDING THE PIPES FOR LOOSE-FILL INSULATION SYSTEMS
        READ (8,*) KASP
      END IF
C  READING IN INPUT DATA FOR CALCULATIONS OF PIPE HEAT LOSS AND
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C  GENERATION OF THE COORDINATES OF NODAL POINTS
      CALL PIPEN(X,Y,ITREN,TRTK,D,F,INXK)
      CALL TWOPIP(1,ITREN)
      CALL EQUIK(TAS,TDEL,KASP)
      IF(ICALB.EQ.1) THEN
      WRITE(7,5)
5     FORMAT('   X(M),M=1,NN')
      WRITE(7,7) (X(I),I=1,NN)
7     FORMAT(10F7.2)
      WRITE(7,10)
10    FORMAT('   Y(M),M=1,NN')
      WRITE(7,7) (Y(I),I=1,NN)
      END IF
C  CALCULATIONS OF UNDISTURBED EARTH TEMPERATURES AT VARIOUS DEPTHS
      CALL TGO(TGX,PI,Y)
C  INITIALIZATION OF THE INDEX OF CONVECTION BOUNDARY FOR ELEMENT N
      DO 12 N=1,NE
12    IXCB(N)=O
C  PERFORM ITERATIONS TO ACCOUNT FOR THE TEMPERATURE EFFECTS ON SOIL
C  AND INSULATION THERMAL CONDUCTIVITIES
         DO 24 I=1,NN
24          T(I)=TG
       DO 26 I=1,NE
          HIJ(I)=0.
          HJK(I)=0.
          HKI(I)=0.
          TIJ(I)=0.
          TJK(I)=0.
          TKI(I)=0.
          HHIJ(I)=0.
          HHJK(I)=0.
          HHKI(I)=0.
26     CONTINUE
C     READING IN THE ELEMENT NUMBER AND ITS NODAL POINTS AND THE
C     MATERIAL TYPE, WHICH INCLUDES
C        MAT(J) = 1  CONCRETE TRENCH
C               = 2  PIPE INSULATION
C               = 3  AIR SPACE SURROUNDING THE PIPES IN TRENCH
C               = 4  SOIL SURROUNDING THE TRENCH
      DO 30 I=1,NE
         READ(9,*) J,(NODE(J,K),K=1,3),MAT(J)
         IF (MAT(J).EQ.1) CC(J)=KTCT/12.
         IF (MAT(J).EQ.2) CC(J)=KI/12.
         IF (MAT(J).EQ.3) CC(J)=KASP/12.
         IF (MAT(J).EQ.4) CC(J)=KG/12.
30    CONTINUE
C   READ IN TOTAL NUMBER OF ELEMENTS HAVING BOUNDARY SEGMENTS SUBJECT
C   TO CONVECTIVE HEAT TRANSFER
      READ (9,*) NECB
C   READ IN ELEMENT NUMBER, CONVECTIVE HEAT TRANSFER COEFFICIENTS,
C   AND AMBIENT TEMPERATURES FOR THREE BOUNDARY SEGMENTS
      DO 35 I=1,NECB
        READ (9,*) M,HIJ(M),HJK(M),HKI(M),TIJ(M),TJK(M),TKI(M)
        IXCB(M)=1
35    CONTINUE
      ITER=1
38    DO 40 I=1,NN
      DO 40 J=1,NN
          Q(I)=0.
          KK(I,J)=0.
          QQ(I)=0.
          CK(I,J)=0.
          DQ(I)=0.
          VV(I)=1.0
          INDX(I)=1
40    CONTINUE
      L=1.
      DO 180 M=1,NE
        I=NODE(M,1)
        J=NODE(M,2)
        K=NODE(M,3)
        IF(MAT(M).EQ.3) CC(M)=KASP/12.
        C=CC(M)
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      IF ((INXK.EQ.0).OR.(ITER.EQ.1)) GO TO 60
C  DETERMINE SOIL AND INSULATION THERMAL CONDUCTIVITIES BASED ON THE
C  MEAN TEMPERATURES
      TM=(T(I)+T(J)+T(K))/3.
      IF(MAT(M).EQ.2)  CALL INSULK(TM,C)
      IF(MAT(M).EQ.4)  CALL SOILK(TM,KG,C)
      CC(M)=C
60    XI=X(I)
      XJ=X(J)
      XK=X(K)
      YI=Y(I)
      YJ=Y(J)
      YK=Y(K)
      CXX=C
      CXY=0.
      CYX=0.
      CYY=C
      B2I=YJ-YK
      B3I=XK-XJ
      B2J=YK-YI
      B3J=XI-XK
      B2K=YI-YJ
      B3K=XJ-XI
C   CALCULATE THE ELEMENT AREA
      SA=0.5*(XJ*B2J+XI*B2I+XK*B2K)
      SA=ABS(SA)
      A2=SA*2.
      AS(M)=A2
      B2I=B2I/A2
      B3I=B3I/A2
      B2J=B2J/A2
      B3J=B3J/A2
      B2K=B2K/A2
      B3K=B3K/A2
      B2IZ(M)=B2I
      B3IZ(M)=B3I
      B2JZ(M)=B2J
      B3JZ(M)=B3J
      B2KZ(M)=B2K
      B3KZ(M)=B3K
      BII=SA*L*(B2I*B2I*CXX+B2I*B3I*CXY+B3I*B2I*CYX+B3I*B3I*CYY)
      BIJ=SA*L*(B2I*B2J*CXX+B2I*B3J*CXY+B3I*B2J*CYX+B3I*B3J*CYY)
      BIK=SA*L*(B2I*B2K*CXX+B2I*B3K*CXY+B3I*B2K*CYX+B3I*B3K*CYY)
      BJI=SA*L*(B2J*B2I*CXX+B2J*B3I*CXY+B3J*B2I*CYX+B3J*B3I*CYY)
      BJJ=SA*L*(B2J*B2J*CXX+B2J*B3J*CXY+B3J*B2J*CYX+B3J*B3J*CYY)
      BJK=SA*L*(B2J*B2K*CXX+B2J*B3K*CXY+B3J*B2K*CYX+B3J*B3K*CYY)
      BKI=SA*L*(B2K*B2I*CXX+B2K*B3I*CXY+B3K*B2I*CYX+B3K*B3I*CYY)
      BKJ=SA*L*(B2K*B2J*CXX+B2K*B3J*CXY+B3K*B2J*CYX+B3K*B3J*CYY)
      BKK=SA*L*(B2K*B2K*CXX+B2K*B3K*CXY+B3K*B2K*CYX+B3K*B3K*CYY)
      KK(I,I)=KK(I,I)+BII
      KK(I,J)=KK(I,J)+BIJ
      KK(I,K)=KK(I,K)+BIK
      KK(J,I)=KK(J,I)+BJI
      KK(J,J)=KK(J,J)+BJJ
      KK(J,K)=KK(J,K)+BJK
      KK(K,I)=KK(K,I)+BKI
      KK(K,J)=KK(K,J)+BKJ
      KK(K,K)=KK(K,K)+BKK
      IF(IXCB(M).EQ.0) GO TO 130
C   ADDITION OF CONVECTION TERMS TO THE ELEMENT MATRIX TO ACCOUNT
C   FOR CONVECTION ON BOUNDARY
C   READING IN CONVECTIVE HEAT TRANSFER COEFFICIENTS AND AMBIENT
C   TEMPERATURES FOR THREE BOUNDARY SEGMENTS
      HHIJ(M)=HIJ(M)*L*SQRT((X(I)-X(J))**2+(Y(I)-Y(J))**2)/6.
      HHJK(M)=HJK(M)*L*SQRT((X(J)-X(K))**2+(Y(J)-Y(K))**2)/6.
      HHKI(M)=HKI(M)*L*SQRT((X(K)-X(I))**2+(Y(K)-Y(I))**2)/6.
      KK(I,I)=HHIJ(M)*2.+HHKI(M)*2.+KK(I,I)
      KK(I,J)=HHIJ(M)+KK(I,J)
      KK(I,K)=HHKI(M)+KK(I,K)
      KK(J,I)=HHIJ(M)+KK(J,I)
      KK(J,J)=HHIJ(M)*2+HHJK(M)*2.+KK(J,J)
      KK(J,K)=HHJK(M)+KK(J,K)
      KK(K,I)=HHKI(M)+KK(K,I)
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      KK(K,J)=HHJK(M)+KK(K,J)
      KK(K,K)=HHJK(M)*2.+HHKI(M)*2.+KK(K,K)
      HHIJ(M)=TIJ(M)*3.*HHIJ(M)
      HHJK(M)=TJK(M)*3.*HHJK(M)
      HHKI(M)=TKI(M)*3.*HHKI(M)
130   Q(I)=Q(I)+HHIJ(M)+HHKI(M)
      Q(J)=Q(J)+HHIJ(M)+HHJK(M)
      Q(K)=Q(K)+HHJK(M)+HHKI(M)
180   CONTINUE
C   DETERMINE IF FINITE ELEMENT GRID DATA ARE TO BE PRINTED OUT
      IF ((ICALB.EQ.1).AND.(IREPT.EQ.MREPT)) THEN
      WRITE(7,185)
185   FORMAT('       M     I     J     K     MAT.     C')
      DO 190 I=1,NE
      WRITE(7,187) I,(NODE(I,J),J=1,3),MAT(I),CC(I)
187   FORMAT(1X,5I6,F10.4)
190   CONTINUE
      END IF
C   DETERMINE OUTER SURFACE TEMPERATURES OF UNDERGROUND PIPES
      DO 200 I=1,8
        T(I)=TP1
        II=I+8
        T(II)=TP2
200   CONTINUE
C   DETERMINE OUTER BOUNDARY TEMPERATURES OF EARTH REGION
      CALL TGXX(T,TGX,MONTH)
      MZ1=MZ+1
      DO 260 I=MZ1,NN
        SUM=0.
        DO 250 J=1,MZ
250       SUM=SUM+KK(I,J)*T(J)
        QQ(I)=Q(I)-SUM
260   CONTINUE
      IF(ICALB.EQ.1) THEN
         WRITE(7,280)
280      FORMAT(6X,'QQ    ARRAY')
         WRITE(7,285) (QQ(I),I=1,NN)
285      FORMAT (6E12.5)
      END IF
C  RENAMING OF MATRICES
      MN=NN-MZ
      DO 300 I=1,MN
         K=MZ+I
        DO 290 J=1,MN
           KL=MZ+J
290        CK(I,J)=KK(K,KL)
           XT(I)=T(K)
           DQ(I)=QQ(K)
300      CONTINUE
C  SOLUTION OF SIMULTANEOUS EQUATIONS
C  SET PHYSICAL DIMENSION OF MATRIX A
       NP=150
      CALL SOLVLE(CK,MN,NP,INDX,VV,DQ)
      DO 310 I=1,MN
          K=MZ+I
          T(K)=DQ(I)
310    CONTINUE
C   CALCULATE AVERAGE SURFACE TEMPERATURE OF INSULATED PIPES
      SU1=0.0
      SU2=0.0
      DO 312 I=1,8
        L1=I+71
        L2=I+79
        SU1=SU1+T(L1)
        SU2=SU2+T(L2)
312   CONTINUE
      TSM1=SU1/8.
      TSM2=SU2/8.
C   DETERMINE THE EFFECTIVE SURFACE TEMPERATURE OF INSULATED PIPES
      DIP1=D1+2.*THK1
      DIP2=D2+2.*THK2
      TEFPS=(DIP1*TSM1+DIP2*TSM2)/(DIP1+DIP2)
C   CALCULATE THE INNER SURFACE TEMPERATURE OF THE TRENCH
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      SU3=0.0
      DO 314 I=1,16
        L3=I+36
314     SU3=SU3+T(L3)
      TEFTS=SU3/16.
C   DETERMINE THE TEMPERATURE DIFFERENCE BETWEEN THE INSULATED PIPES
C   AND THE TRENCH INNER SURFACE
      TDEL=ABS(TEFPS-TEFTS)
      TAS=(TEFPS+TEFTS)/2.
      CALL EQUIK(TAS,TDEL,KASP)
      WRITE(7,320) KASP
320   FORMAT('  KASP=',F10.4,2X,'(BTU-IN./H-FT**2-DEG F)')
330   FORMAT('  TEMPERATURE ARRAY : T(I), I=1,NN ')
C  CALCULATE THE MEAN VALUES OF INSULATION THERMAL CONDUCTIVITY FOR
C  PIPES 1 AND 2
350   SKI1=0.
      SKI2=0.
      DO 400 LN=1,16
         LM=MINS+LN-1
         LL=LM+16
         SKI1=SKI1+CC(LM)
         SKI2=SKI2+CC(LL)
400   CONTINUE
      KIX1=SKI1/16.
      KIX2=SKI2/16.
      R1=D1/24.
      R2=D2/24.
      TH1X=TH1/12.
      TH2X=TH2/12.
      IF(ICALB .EQ. 0) THEN
        MO=11
        IF(IREPT .EQ. MREPT) MO=7
      END IF
C  CALCULATIONS OF THE HEAT LOSSES FROM THE UNDERGROUND PIPES
      CALL  PIPEHL(T,R1,R2,TH1X,TH2X,KIX1,KIX2,MO,QTX)
      HLOSS=QTX
      IF(ITER.EQ.1) HLOSX=0.
C   DETERMINE IF PIPE HEAT LOSS VALUE HAS CONVERGED, OR CONTINUE
C   ITERATIONS IF REQUIRED
      DELQT=ABS(HLOSS-HLOSX)/HLOSS
      IF(DELQT.LE. 0.010) GO TO 2010
      ITER=ITER+1
      HLOSX=HLOSS
      GO TO 38
2000  WRITE (7,2005)
2005  FORMAT (1X,'THERE ARE SOME ERRORS IN INPUT DATA')
2010  IF(ICALB .EQ. 1) THEN
      WRITE (7,330)
      WRITE (7,285) (T(I),I=1,NN)
      END IF
      STOP
      END

      SUBROUTINE TGO(TGX,PI,Y)
C   THIS SUBROUTINE CALCULATES THE UNDISTURBED EARTH TEMPERATURES
C   AT VARIOUS DEPTHS
      DIMENSION TGX(12,5),Y(150)
C     READING IN THE ANUAL AVERAGE TEMPERATURE AND AMPLITUDE OF THE
C     MONTHLY NORMAL TEMPERATURE CYCLE OF THE SITE, IN DEG F, AND
C     THERMAL DIFFUSIVITY OF SOIL, IN FT**2/H.
      READ (8,*) AO,BO,DIFF
      W=2.*PI/12.
      WZ=2.*PI/(8760*DIFF*2)
      ZZ=SQRT(WZ)
      DO 1 I=1,12
      DO 1 J=1,5
      Z=ZZ*Y(29-J)
1     TGX(I,J)=AO+BO*EXP(-Z)*SIN(W*(I-3)-Z)
      RETURN
      END

      SUBROUTINE TGXX(T,TGX,MONTH)
C THIS SUBROUTINE PROVIDES OUTER BOUNDARY TEMPERATURES OF EARTH REGION
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      DIMENSION T(150),TGX(12,5)
      T(28)=TGX(MONTH,1)
      DO 1 I=1,8
         II=I+28
1        T(II)=T(28)
      DO 5 I=2,5
         I15=I+15
         JI=29-I
         T(I15)=TGX(MONTH,I)
         T(JI)=TGX(MONTH,I)
5     CONTINUE
      DO 10 I=1,3
         I20=I+20
10     T(I20)=TGX(MONTH,5)
      RETURN
      END

      SUBROUTINE INSULK(TM,C)
C  THIS SUBROUTINE DETERMINES THE THERMAL CONDUCTIVITY OF PIPE
C  INSULATION (CALCIUM SILICATE) AS A FUNCTION OF THE MEAN
C  TEMPERATURE.
      REAL KN(16),KINS
      DIMENSION TN(16)
      DATA KN /0.375,0.40,0.42,0.45,0.48,0.50,0.53,0.555,0.58,0.61,
     & 0.63,0.66,0.68,0.74,0.82,0.90/
      DO 5 J=1,16
      IF(J .LE. 13) THEN
         TN(J)=100.+(J-1)*50.
      ELSE
         TN(J)=700.+(J-13)*100.
      END IF
5     CONTINUE
      IF(TM .GT. TN(1)) GO TO 10
      KINS=KN(1)
      GO TO 100
10    IF(TM .LT. TN(16)) GO TO 20
      KINS=KN(16)
      GO TO 100
20    DO 50 I=1,15
      T1=TM-TN(I)
      IF(T1 .NE. 0.) GO TO 30
      KINS=KN(I)
      GO TO 100
30    T2=TN(I+1)-TM
      IF(T2 .NE. 0.) GO TO 40
      KINS=KN(I+1)
      GO TO 100
40    P=T1*T2
      IF(P .LT. 0.) GO TO 50
      KINS=KN(I)+T1*(KN(I+1)-KN(I))/(TN(I+1)-TN(I))
      GO TO 100
50    CONTINUE
100   C=KINS/12.
      RETURN
      END

      SUBROUTINE  SOILK(TM,KG,C)
C THIS ROUTINE DETERMINES THE THERMAL CONDUCTIVITY OF SOIL AS A
C FUNCTION OF MEAN TEMPERATURES.
      REAL K(14),KG
      DIMENSION TX(14)
      DATA K/1.1,1.1,1.1,1.0,0.4,0.31,0.25,0.19,0.15,0.11,0.09,0.07,
     & 0.05,0.05/
      DO 1 I=1,14
1        TX(I)=50.+(I-1)*25.
      IF(TM.GT.TX(1)) GO TO 5
      ZK=1.1
      GO TO 50
5     IF(TM.LT.TX(14)) GO TO 10
      ZK=0.05
      GO TO 50
10    DO 25 I=1,13
      T1=TM-TX(I)
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      IF(T1.NE.0) GO TO 15
      ZK=K(I)
      GO TO 50
15    CONTINUE
      T2=TM-TX(I+1)
      IF(T2.NE.0.) GO TO 20
      ZK=K(I+1)
      GO TO 50
20    CONTINUE
      P=T1*T2
      IF(P.GT.0) GO TO 25
      ZK=K(I+1)+T2*(K(I+1)-K(I))/25.
      GO TO 50
25    CONTINUE
50    C=ZK*KG/(1.1*12.)
      RETURN
      END

      SUBROUTINE PIPEHL(T,R1,R2,TH1,TH2,ZKS1,ZKS2,MO,QT)
C  THIS SUBROUTINE CALCULATES THE AVERAGE TEMPERATURE DROPS ACROSS THE
C  PIPE INSULATIONS AND THE RATES OF HEAT LOSS FROM THE UNDERGROUND
C  PIPES IN TRENCH SYSTEM
      DIMENSION T(150)
      PI=4.*ATAN(1.)
      SUM1=0.
      SUM2=0.
      N1=8
      DO 1 I=1,N1
         K1=I
         K2=I+8
         K3=I+71
         K4=I+79
         SUM1=SUM1+T(K1)-T(K3)
         SUM2=SUM2+T(K2)-T(K4)
1     CONTINUE
      T1=SUM1/N1
      T2=SUM2/N1
      ZKIS1=ZKS1*12.
      ZKIS2=ZKS2*12.
      Q1=ZKS1*2.*PI*T1/LOG((R1+TH1)/R1)
      Q2=ZKS2*2.*PI*T2/LOG((R2+TH2)/R2)
      QT=Q1+Q2
      IF(MO .EQ. 11) GO TO 50
      WRITE(MO,5) ZKIS1,ZKIS2
5     FORMAT(/'  AVERAGE VALUES OF PIPE INSULATION THERMAL',
     &' CONDUCTIVITY :',/,'   KI1 = ',F10.3,'   KI2 = ',F10.3,
     & '   BTU-IN/H-FT**2-DEG F ')
      WRITE(MO,10) T1,T2
10    FORMAT(/'  AVERAGE TEMPERATURE DROPS ACROSS INSULATION : ',/,
     & '   T1= ',F10.2,'   T2= ',F10.2,'  DEG F')
      WRITE(MO,20) Q1,Q2,QT
20    FORMAT(/,2X,'HEAT LOSSES FROM UNDERGROUND PIPES :'/'   Q1=',
     & F10.2, '   Q2=',F10.2,'   QT=',F10.2,'  BTU/H-FT')
50    RETURN
      END

      SUBROUTINE PIPEN(X,Y,ITREN,TRTK,D,F,INXK)
C THIS SUBROUTINE READS IN THE INPUT DATA TO BE USED FOR CALCULATIONS
C OF THE HEAT LOSSES FROM THE UNDERGROUND PIPES AND GENERATES X AND Y-
C COORDINATES OF NODAL POINTS FOR THE TWO PIPE SYSTEM.
      REAL KII,KIG,KI,KG
      DIMENSION X(150),Y(150)
      COMMON /PP/TP1,TP2,KII,KIG,DI1,DI2,THI1,THI2,B1,B2,S1,S2,TG,
     & WW,HY,MONTH
      COMMON /EK/D1P,D2P,A,B,THK1,THK2
C READ TEMPERATURE OF PIPE NUMBERS 1 AND 2, IN DEG F
      READ (8,*) TP1,TP2
C READ THERMAL CONDUCTIVITY OF THERMAL INSULATION AND SOIL,
C RESPECTIVELY, IN BTU-IN./H-FT**2 - DEG F, AND INDEX OF THERMAL
C CONDUCTIVITY : INXK = 0  CONSTANT THERMAL CONDUCTIVITY
C                     = 1  TEMPERATURE DEPENDENT THERMAL CONDUCTIVITY
      READ (8,*) KII,KIG,INXK
C READING IN THE OUTSIDE DIAMETERS OF STEEL PIPES 1 AND 2, IN INCHES
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      READ (8,*) DI1,DI2
C READING IN THE THICKNESS OF THERMAL INSULATION USED FOR PIPES 1
C AND 2, RESPECTIVELY, IN INCHES
      READ (8,*) THI1,THI2
C READ THE DEPTHS FROM GROUND SURFACE TO THE CENTERS OF PIPES 1 AND
C 2, RESPECTIVELY, IN FT.
      READ (8,*) B1,B2
C   READING IN THE HORIZONTAL DISTANCES (IN FT.) FROM VERTICAL
C   CENTERLINE OF THE TRENCH TO CENTERS OF PIPES 1 AND 2,
C   RESPECTIVELY, AND THE AVERAGE EARTH TEMPERATURE, IN DEG F.
      READ (8,*) S1,S2,TG
C   READ IN THE WIDTH AND DEPTH OF EARTH REGION SURROUNDING THE
C   UNDERGROUND SYSTEM, IN FT.
      READ (8,*) WW,HY
      WRITE(7,10) TP1,TP2,KII,KIG,DI1,DI2
10    FORMAT('   TP1    TP2     KI     KG     D1      D2'/6F7.2)
      WRITE(7,20) THI1,THI2,B1,B2,S1,S2,TG
20    FORMAT('   THI1   THI2    DP1    DP2     S1     S2     TG',
     & /7F7.2)
      WRITE(7,30) WW,HY,MONTH
30    FORMAT('     WW     HY   MONTH '/2F7.2,I7)
C   READ IN THE INNER WIDTH AND HEIGHT OF THE TRENCH, OR THE WIDTH
C   AND HEIGHT OF THE INNER EARTH REGION FOR LOOSE-FILL INSULATION
C   SYSTEMS, IN FT.
      READ (8,*) A,B
C   CHANGE TO ENGINEERING UNITS
      D1=DI1/12.
      R1=D1*0.5
      D2=DI2/12.
      R2=D2*0.5
      D1P=DI1/12.
      D2P=DI2/12.
      KI=KII/12.
      KG=KIG/12.
      IF(ITREN .EQ. 1) THEN
        W=A+2*TRTK/12
        H=B+D+F
      ELSE
        W=2*A
        H=2.*B+D
      END IF
      WRITE(7,40) W,H,D,F,A,B,WW,HY
40    FORMAT('     W      H      D      F      A      B     WW     HY'
     &,/,8F7.2)
      PI=4.*ATAN(1.)
      TH1=THI1/12.
      TH2=THI2/12.
      THK1=THI1/12.
      THK2=THI2/12.
C   DETERMINE THE X AND Y-COORDINATES OF CONCRETE TRENCH COVER,
C   WALLS,AND FLOOR (NODAL POINTS 30 TO 34, 37 TO 52, AND 53 TO 63)
      DO 50 I=1,5,2
        I29=I+29
        X(I29)=W-(I-1)*W/4.
50      Y(I29)=0.
      DO 60 I=1,3,2
        I30=I+30
        X(I30)=(W+A)*0.5 - A*(I-1)*0.5
60      Y(I30)=0.
      DO 65 I=1,4
        I36=I+36
        I40=I+40
        I44=I+44
        I48=I+48
        I1=I-1
        X(I36)=(W-A)*0.5
        Y(I36)=D+I1*B/4.
        X(I40)=0.5*(W-A)+I1*A/4.
        Y(I40)=D+B
        X(I44)=(W+A)*0.5
        Y(I44)=(D+B)-I1*B/4.
        X(I48)=0.5*(W+A)-I1*A/4.
        Y(I48)=D
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65    CONTINUE
      DO 70 I=1,3
         I52=I+52
         I56=I+56
         I60=I+60
         X(I52)=0.0
         Y(I52)=D+B*(I-1)/2.
         X(I56)=(W-A)*0.5+(I-1)*A*0.5
         Y(I56)=H
         X(I60)=W
         Y(I60)=D+(3-I)*B/2.
70    CONTINUE
         X(56)=0.0
         Y(56)=H
         X(60)=W
         Y(60)=H
C   THE X AND Y-COORDINATES OF OUTER BOUNDARY EARTH SURROUNDING THE
C   SHALLOW TRENCH (NODAL POINTS 17 TO 29,35,36, AND 64 TO 71)
         X(17)=-WW
         Y(17)=0.5*H
         X(27)=W+WW
         Y(27)=0.5*H
      DO 75 I=1,3
         I17=I+17
         I20=I+20
         I23=I+23
         X(I17)=-WW
         Y(I17)=H+HY*(I-1)*0.5
         X(I20)=W*(I-1)*0.5
         Y(I20)=H+HY
         X(I23)=W+WW
         Y(I23)=H+HY*(3-I)*0.5
75    CONTINUE
      DO 80 I=1,2
         I27=I+27
         I34=I+34
         I63=I+63
         I69=I+69
         X(I27)=W+WW*(3-I)*0.5
         Y(I27)=0.
         X(I34)=-WW*0.5*I
         Y(I34)=0.
         X(I63)=-WW*0.5
         Y(I63)=H*I*0.5
         X(I69)=W+WW*0.5
         Y(I69)=H*(3-I)*0.5
80    CONTINUE
      DO 85 I=1,4
         I65=I+65
         X(I65)=W*(I-1)/3.
85       Y(I65)=H+HY*0.5
C   X AND Y-COORDINATES OF THE CENTERS OF THE PIPES
      XC1=W*0.5 - S1
      YC1=B1
      XC2=W*0.5 + S2
      YC2=B2
      WRITE(7,90) XC1,YC1,XC2,YC2
90    FORMAT('    XC1    YC1    XC2    YC2'/4F7.3)
C   THE X AND Y-COORDINATES OF NODAL POINTS AT THE INNER SURFACES
C   OF PIPE INSULATION AND OUTER SURFACES OF THE INSULATED PIPES
C   (NODAL POINTS 1 TO 16, AND 72 TO 87)
      DO 95 I=1,8
         THETA=2.*PI*I/8.
         I8=I+8
         I71=I+71
         I79=I+79
         X(I)=XC1+0.5*D1*SIN(THETA)
         Y(I)=YC1+0.5*D1*COS(THETA)
         X(I8)=XC2+0.5*D2*SIN(THETA)
         Y(I8)=YC2+0.5*D2*COS(THETA)
         X(I71)=XC1+(TH1+0.5*D1)*SIN(THETA)
         Y(I71)=YC1+(TH1+0.5*D1)*COS(THETA)
         X(I79)=XC2+(TH2+0.5*D2)*SIN(THETA)
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         Y(I79)=YC2+(TH2+0.5*D2)*COS(THETA)
95     CONTINUE
C    THE X AND Y-COORDINATES OF NODAL POINTS IN AIR SPACE SURROUNDING
C    THE PIPES INSIDE THE TRENCH (NODAL POINTS 88 TO 101)
        YUP=0.5*(Y(75)-Y(51))
        YUPR=0.5*(Y(83)-Y(51))
        IF (YUPR.LT.YUP) YUP=YUPR
        XLT=0.5*(X(77)-X(39))
        YLO=0.5*(Y(43)-Y(79))
        YLOW=0.5*(Y(43)-Y(87))
        IF (YLOW.LT.YLO) YLO=YLOW
        XRT=0.5*(X(47)-X(81))
      DO 100 I=1,3
         I87=I+87
         I90=I+90
         I93=I+93
         I96=I+96
         X(I87)=0.5*(W+A)-0.25*A*I
         Y(I87)=D+YUP
         X(I90)=0.5*(W-A)+XLT
         Y(I90)=D+0.25*B*I
         X(I93)=0.5*(W-A)+0.25*A*I
         Y(I93)=D+B-YLO
         X(I96)=0.5*(W+A)-XRT
         Y(I96)=D+B-0.25*B*I
100   CONTINUE
      DO 120 I=1,2
         II=I+99
         X(II)=X(51)
         Y(II)=D+YUP+(B-YUP-YLO)*I/3.
120   CONTINUE
      RETURN
      END

      SUBROUTINE TWOPIP(IREPT,ITREN)
C  THIS SUBROUTINE DETERMINES THE HEAT LOSSES FROM TWO PIPES TO THE
C  UNDERGROUND SURROUNDING THE HEAT DISTRIBUTION SYSTEM.
      REAL KII,KIG
      COMMON /PP/T1,T2,KII,KIG,DI1,DI2,THI1,THI2,B1,B2,S1,S2,TG,
     & WW,HY,MONTH
      PI=4.*ATAN(1.)
      X1=2.*PI
      R1=DI1/24.
      R2=DI2/24.
      TH1X=THI1/12.
      TH2=THI2/12.
      ZK1=KII/12.
      ZK2=ZK1
      D1=B1
      D2=B2
      ZKS=KIG/12.
      DO 10 I=1,IREPT
2     TH1=TH1X+0.1*(I-1)
      TH2=TH1
      S=S1+S2
      A=R1+R2+TH1+TH2+0.05
      THI1=TH1*12.
      IF(ITREN.EQ.1) A=S
      C1=X1*ZK1/LOG((R1+TH1)/R1)
      C2=X1*ZK2/LOG((R2+TH2)/R2)
      P11=1.+C1/(X1*ZKS)*LOG((2*D1)/(R1+TH1))
      P12=C2/(X1*ZKS)*LOG((A*A+(D1+D2)**2)/(A*A+(D1-D2)**2))*0.5
      P21=C1/(X1*ZKS)*LOG((A*A+(D1+D2)**2)/(A*A+(D1-D2)**2))*0.5
      P22=1.+C2/(X1*ZKS)*LOG((2*D2)/(R2+TH2))
      DEL=P12*P21-P11*P22
      ZKP1=C1*(P12-P22)/DEL
      ZKP2=C2*(P21-P11)/DEL
      TP1=(P12*T2-P22*T1)/(P12-P22)
      TP2=(P21*T1-P11*T2)/(P21-P11)
      Q1=ZKP1*(TP1-TG)
      Q2=ZKP2*(TP2-TG)
      QT=Q1+Q2
      TAVG=(T1+T2)*0.5
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```
      ZK=QT/(TAVG-TG)
      WRITE(7,6) DI1,DI2,S1,S2,THI1,KII,KIG,T1,T2
6     FORMAT('  DI1   DI2    S1    S2  THI1   KII    KIG    TP1    TP2',
     &/,7F6.2,1X,2F6.0)
      WRITE(7,8) Q1,Q2,QT,ZK
8     FORMAT('    Q1     Q2     QT         KP'/,3F7.2,2X,F6.3/)
10    CONTINUE
      RETURN
      END

      SUBROUTINE EQUIK(TAS,TDEL,KASP)
C   THIS ROUTINE CALCULATES EQUIVALENT THERMAL CONDUCTIVITY OF AIR
C   SPACE SURROUNDING THE PIPES IN A SHALLOW TRENCH
      REAL KASP
      COMMON /EK/D1P,D2P,A,B,THK1,THK2
      PI=4.*ATAN(1.)
C   CALCULATE THERMAL CONDUCTIVITY, IN BTU-FT/H-FT**2-DEG F, AND
C   KINEMATIC VISCOSITY, IN FT**2/S, OF AIR
      THKAIR=0.01319 + TAS*2.5E -5
      VAIR=1.2624E -4 + TAS*5.4E -7
C   CALCULATE THE EFFECTIVE DIAMETERS OF THE RECTANGULAR TRENCH
C   AND THE INSULATED PIPES, IN FT, AND THE CHARACTERISTIC LENGTH
C   OF AIR SPACE, IN FT
      DEFTRN=2.0 * (A+B)/PI
      DEFPIP=(D1P+2.*THK1)+(D2P+2.*THK2)
      CL=ABS(DEFTRN - DEFPIP)
C   CALCULATE THE PRANDTL NUMBER OF AIR , AND GRASHOF NUMBER AND
C   EQUIVALENT THERMAL CONDUCTIVITY, IN BTU-IN/H-FT**2-DEG F, OF
C   AIR SPACE
      PRANTL=0.71849 - TAS * 1.275E -4
      GRASOF=32.2 * TDEL *(CL**3.)/((VAIR**2.)*(TAS+459.7))
      KASP=12.*THKAIR*0.42*(PRANTL*GRASOF)**0.219
      RETURN
      END

      SUBROUTINE SOLVLE(A,N,NP,INDX,VV,B)
C   GIVEN AN NXN MATRIX A, WITH PHYSICAL DIMENSION NP, THIS ROUTINE
C   REPLACE IT BY THE LU DECOMPOSITION OF A ROWWISE PERMUTATION OF
C   ITSELF. INDX IS AN OUTPUT VECTOR WHICH RECORD THE ROW PERMUTATION
C   EFFECTED BY THE PARTIAL PIVOTING; VV IS VECTOR OF SCALING FACTORS.
C
C   THIS ROUTINE IS USED TO SOLVE THE LINEAR SET OF EQUATIONS :
C   [A][X]=[B]
C
      DIMENSION A(NP,NP),INDX(N),VV(N),B(N)
C
C   FORM IMPLICIT SCALING VECTOR VV
C
      DO 12 I=1,N
        AAMAX = 0.0
        DO 11 J=1,N
         IF(ABS(A(I,J)).GT.AAMAX) AAMAX=ABS(A(I,J))
   11   CONTINUE
        IF(AAMAX.EQ.0.) THEN
          WRITE(7,100) I
100     FORMAT(1X,'ERROR:SINGULAR MATRIX - ZERO ROW : ROW',I5)
          RETURN
        END IF
       VV(I) = 1.0/AAMAX
   12 CONTINUE
C
C   CROUT METHOD: LOOP OVER COLUMNS
C
      DO 19 J=1,N
        DO 14 I=1,J-1
          SUM = A(I,J)
          DO 13 K=1,I-1
            SUM = SUM - A(I,K)*A(K,J)
   13     CONTINUE
        A(I,J) = SUM
   14   CONTINUE
C
C   PIVOT IMPLEMENTATION
```

```
 C
         AAMAX = 0.0D0
         DO 16 I=J,N
           SUM = A(I,J)
           DO 15 K=1,J-1
             SUM = SUM - A(I,K)*A(K,J)
    15     CONTINUE
           A(I,J) = SUM
           DUM = VV(I)*ABS(SUM)
           IF(DUM.GE.AAMAX) THEN
             IMAX = I
             AAMAX = DUM
           ENDIF
    16   CONTINUE

         IF(J.NE.IMAX) THEN
           DO 17 K=1,N
             DUM = A(IMAX,K)
             A(IMAX,K) = A(J,K)
             A(J,K) = DUM
    17     CONTINUE
         VV(IMAX) = VV(J)
       ENDIF
       INDX(J) = IMAX
       IF(A(J,J).EQ.0.0) THEN
         WRITE(7,110) J
110     FORMAT(1X,'ERROR: SINGULAR MATRIX - ZERO " DIAG " : ROW',I5)
         RETURN
       END IF
       IF(J.NE.N) THEN
         DUM = 1.0/A(J,J)
         DO 18 I=J+1,N
           A(I,J) = A(I,J)*DUM
    18   CONTINUE
       END IF
    19 CONTINUE
C
C    FORWARD SUBSTITUTION
C
       II = 0
       DO 22 I=1,N
         LL = INDX(I)
         SUM = B(LL)
         B(LL) = B(I)
         IF(II.NE.0) THEN
         DO 21 J=II,I-1
           SUM = SUM - A(I,J)*B(J)
    21     CONTINUE
         ELSE IF(SUM.NE.0.0) THEN
          II = I
         END IF
         B(I) = SUM
    22 CONTINUE
C
C    BACKWARD SUBSTITUTION
C
       DO 24 I=N,1,-1
         SUM = B(I)
         IF(I.LT.N) THEN
           DO 23 J=I+1,N
           SUM = SUM - A(I,J)*B(J)
    23     CONTINUE
         END IF
         B(I) = SUM/A(I,I)
    24 CONTINUE
       RETURN
       END
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NBS-114A (REV. 2-8C)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO.	2. Performing Organ. Report No.	3. Publication Date
	NISTIR 89-4134		OCTOBER 1989

4. TITLE AND SUBTITLE

Quantification of Heat Losses Through Structural Supports for Shallow Trench Heat Distribution Systems

5. AUTHOR(S)

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
U.S. DEPARTMENT OF COMMERCE
GAITHERSBURG, MD 20899

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

Tri-Service Building Materials Committee
Headquarters, U. S. Army Corps of Engineers
Washington, D.C. 20314-1000

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Shallow trench heat distribution systems generally contain numerous structural supports which are often in direct contact with hot carrier pipes and form highly conductive heat flow paths, and are major sources of heat loss. Quantification of the heat loss caused by thermal bridges due to pipe supports and prediction of thermal fields were achieved using three finite element computer models of two-dimensional, steady-state heat conduction within a rectangular concrete trench containing two insulated pipes with and without pipe supports, and the surrounding earth. The theoretical basis, computational scheme, and the data input and outputs of the developed computer programs for sample calculations are described. Two trench pipe support systems studied include the horizontal anchoring and the vertical supports. The thermal bridges due to structural supports contribute approximately 17 times more to total heat loss compared to similar pipes with no pipe supports.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Computer program, district heating and cooling, finite element method, heat loss, heat transfer, pipe support system, shallow trench, underground heat distribution system

13. AVAILABILITY

X Unlimited
☐ For Official Distribution. Do Not Release to NTIS
☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
X Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

107

15. Price

A06