A PERSONAL COMPUTER SOLUTION TO THE MODIFIED BERGGREN EQUATION

FINAL REPORT

By

W. Alan Braley

Institute of Water Resources/
Engineering Experiment Station
University of Alaska
Fairbanks, AK 99701

December 1984

Prepared for:

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
DIVISION OF PLANNING
RESEARCH SECTION
2301 Peger Road
Fairbanks, Alaska 99701

TABLE OF CONTENTS

INTRODUCTION

BERG is a computer program which solves the modified Berggren equation to estimate depths of maximum freeze or thaw in multilayered soil systems. The program is written in advanced basic (BASICA) for an IBM PC micro-computer, using the modified Berggren method as described by the Department of the Army and the Air Force (1966) and by Aitken (1968).

The user of BERG is referred to the two previously mentioned reports and to Lunardini (1981) for a complete discussion of the modified Berggren method and its solution. Discussion here is limited to describing several limitations of the multilayered solution provided by the modified Berggren method. Detailed information to aid the BERG user is also given. Program diskettes are available upon request from the Alaska DOT&PF Research Section.

CONSIDERATIONS

The solution of the modified Berggren equation estimates the depth of freeze or thaw in a layered soil by determining the portion of the surface freezing or thawing index required to move the freeze or thaw front down through each successive soil layer. The sum of these layer thicknesses is the total depth of freeze or thaw. The portion of the surface index required to cause the freeze of thaw front to penetrate each layer is directly proportional to the latent heat for the layer, the thermal resistance of the layer, and the summation of the thermal resistances for all layers above the layer. In the modified Berggren method if the latent heat of the material constituting a layer is zero, as may be the case for concrete, asphalt, and rigid foam insulation, then no portion of the surface index is needed for the freeze or thaw front to penetrate the layer. This method of calculation does not allow the freeze or thaw front to be contained within a layer of these types of materials. This error is caused by the fact that the modified Berggren method neglects sensible energy changes in zero latent heat layers as the freeze or thaw front moves through them. The magnitude of this error is increased in insulations due to their high thermal resistance. This problem in the modified Berggren calculation methodology can be alleviated by specifying a small (.001 Btu/ft^3) latent heat for insulation layers. The latent heat of rigid foam

insulation has been set to .001 Btu/ft^3 within this program. By doing this the thermal resistance of the insulation is accounted for when calculating the portion of the surface index needed to move the freeze or thaw front through the insulation. This allows the calculated freeze or thaw front to be contained within the insulation.

Another consideration is the initial temperature regime of the layered system. When the Berggren method is used for calculating the depth of freeze for a location, the layered soil system is assumed to be isothermal at the mean annual temperature for the location. This is, of course, only meaningful for a non-permafrost area and impossible for a permafrost area where the mean annual temperature is below freezing. Therefore, using the modified Berggren method for a permafrost site will yield a meaningless number when calculating freeze depth. A similar problem is encountered when attempting to calculate the thaw depth in areas of seasonal frost where the soil is initially thawed. However, in areas of discontinuous permafrost, such as the interior of Alaska, where the mean annual temperature approaches 32°F, both the depth of freeze and thaw will be meaningful calculations.

PROGRAM OPERATION

Start Up (IBM PC)

The diskette containing the program BERG is self-loading. If the diskette is in the default drive, usually the "A" drive, upon power-up of the computer, the program will load and begin to run. If the system is already powered-up, insert the diskette in the default drive and reset the system, (CRTL-ALT-DEL keys pushed simultaneously).

BERG is divided into several sections allowing easy modification of input parameters and calculation of freeze and thaw depths. There are separate screens which allow the user to modify the environmental parameters and layer properties used in the calculation by using the screen editing capabilities of an IBM-PC. The environmental parameters screen may be selected for viewing or editing by typing "L" (Location), similarly the layer properties screen may be selected by typing "S" (Soil). The methods used for altering these parameters is described in the following sections of this report. To initiate calculation of the freeze and thaw depths a "R" (Run) is typed.

Environmental Parameters

Upon startup, the first screen which appears will be the environmental parameter screen. This screen contains all the environmental parameters required to operate the program. To change the location for which the parameters are displayed, the user may either type the first letter of the location name as listed, or using the cursor control keys to the right of the main keyboard, move the cursor to the number following the title "LOCATION NUMBER", and change this number to the appropriate location number shown in the list.

For any of the locations listed, the default environmental parameters may be changed by moving the cursor to the parameter to be changed and altering it to the desired value. The user should be aware that when one of the default locations is selected, the environmental parameters may be altered and used in a subsequent calculation. However, if the user returns to the location screen, the environmental parameters will be reset to the default values. If the user wishes to avoid this, the location should be changed to 12 ("USER INPUT"). When this is selected, the environmental parameters appearing on the screen become the default values for the "USER INPUT" location. If these parameters are changed, they will remain changed when the user returns to the location screen.

Layered Properties

When "S" is typed, the material properties for each layer may be viewed and altered. To select a given layer, type the layer number. The program will accept up to 9 layers. The number of layers for which parameters are input must be specified by altering the corresponding line of any of the layer properties screens. The material type of each layer may be selected, from the list shown, by changing the material number given in the data set for that layer. For materials, gravel, silt, and sand, the thermal conductivity, latent heat, and heat capacity are calculated by the program based on the moisture content, dry density and the soil type given. If the calculated values of these parameters, or the default parameters for

concrete, asphalt, or insulation are unacceptable, they may be altered by using the cursor control keys and changing the parameter values on the screen. These changes will be used by the program until the user selects another material number for that layer.

The program will check the moisture contents and dry densities specified for each material to insure that the saturation level does not exceed 98%. If an error occurs, the dry density will be automatically adjusted to a value which gives a 98% saturation at the specified moisture content. A warning message will be issued at this point.

Note

When the location or soil screens first appear, or are refreshed by the program, the cursor will not appear on the screen. If the cursor is to be moved to change a parameter, push a cursor control key once to get the cursor back on the screen. Following a change to any parameter, the enter key must be pushed while the cursor appears on the same line in which the parameter was changed.

Running the Program

Once the layer and environmental parameters are set, calculation is initiated by typing "R". The program first calculates the thaw depth and subsequently calculates the depth of freeze. As the calculation proceeds, layer numbers will be displayed on the screen. These correspond to the programs calculation of the freeze or thaw front moving through the layer. When the layer containing the maximum depth of freeze or thaw is reached, an iteration process will begin. This process will determine the position of the freeze/thaw front within the layer. During the iteration the freezing or thawing index, based upon the environmental data input, will be displayed along with the calculated freezing or thawing index. Once the calculated index is within 10 of the actual index, interation stops. Following the calculation of both the freeze and thaw depths, the input parameters and calculated depths of freeze and thaw are displayed. This screen may be directed to a parallel printer (if attached) by pushing the

shift and PrtSc keys simultaneously. If additional runs are desired, the user may type "L" or "S" to return to the corresponding location or soil screen, make modifications to the input parameter, and run the calculation again.

A step by step example solution is given in the Appendix.

IMPLEMENTATION

This report will be distributed to the State of Alaska Department of Transportation and Public Facilities, Division of Design and Construction. The program should be used to calculate freeze and thaw depths when roadway construction will be influenced by ground thawing or when materials are determined to be freeze-thaw sensitive.

ACKNOWLEDGEMENTS

The development of this program was possible through funding provided by the Federal Highway Administration under the Highway Planning and Research Program. Special recognition is given to Billy Connor, Senior Research Engineer, State of Alaska Department of Transportation and Public Facilities, Division of Planning, Research Section, who was instrumental in program design and development, and to Cathy Voigt for preparation of the text.

REFERENCES

Aitken, G.W. and Berg, R.L., 1968. "Digital Solution of Modified Berggren Equation to Calculate Depths of Freeze or Thaw in Multilayered Systems", U.S. Army, CRREL, Special Report 122, Hanover, NH.

Departments of the Army and Air Force, 1966. "Arctic and Subarctic Construction, Calculation Methods for Determination of Depths of Freeze and Thaw in Soils", Department of the Army Technical Manual TM-5-8526m Department of the Air Force Manual AFM 88-19, Chapter 6.

Lunardini, V.J., 1981. "Heat Transfer in Cold Climates", Van Nostrond Reinhold Company, New York, NY, Chapter 10.

APPENDIX

APPENDIX

This appendix presents an example run of the program BERG. Examples of the screens displayed during operation are shown as well as the key sequences used to proceed through the run.

After initiating the operation of the program, the screen in Figure 1 is displayed. This is the environmental parameter screen. At this point a single character, corresponding to the first character on one of the locations shown at the top of the screen may be typed. This would result in a new screen displaying the default parameters for the location selected. For this example, a location of Fairbanks and the associated default environmental parameters are used.

At this point a single character "S" is typed, to select the material property screens for the layer. The screen now displayed is shown in Figure 2. This screen gives the material properties for the first layer. Note that the layer number is given at the top of the screen and the default parameters are displayed. These parameter values must be edited to suit the situation being modeled. In this example, a three layered system will be specified. To relay this information to the program, the number 9, following the title "NUMBER OF LAYERS" is changed to a 3 as follows. Pushing any of the cursor control keys, located on the right of the keyboard, causes the flashing cursor to be displayed immediately to the left of the line title "NUMBER OF LAYERS". Pushing cursor control key "END" moves the cursor immediately to the right of the 9 on this line, the ← cursor key is pushed and a 3 is typed in place of 9. Having made this change, this screen should now appear as shown in Figure 3.

In the previous example, changes were made by moving the cursor to the end of the line on which it first appeared and changing this parameter. The cursor also may be moved up and down on the screen using the cursor control keys. The only requirements when editing data is that only those numbers to the right of the colons (:) are changed, and that any changes are followed by pushing the enter key while the cursor still appears on the line in which data was changed. These requirements also pertain to the location screens.

After the data input for the first layer is completed, a single character "2" is typed to select the screen for the second layer. The only modification required of this screen is to change the thickness of the layer from 1 ft to 4 ft. This screen appears as in Figure 4.

A "3" is now typed, selecting the third layer of the system. In this layer the "MATERIAL NUMBER" is changed to 3, to indicate silt, and the thickness is then modified to 10 feet. This screen should appear as shown in Figure 5.

In this example, only three layers were specified, and parameter data was input for each layer. It is important that layer material data is input for each layer specified. If this is not done the program will display an error when calculation is initiated.

It is best to describe layer properties to a depth greater than the expected maximum freeze and thaw depths. Although the program will expand the bottom layer of the system automatically if the total depth specified is less than the depth of freeze or thaw being calculated, the process will lengthen the required calculation time.

Having input and altered the data as needed for this example, the calculation is then initiated. This is done by typing a single character "R". The screen will then clear and layer numbers will be displayed as the program calculates the thawing index required for the thaw front to penetrate each layer. In this example, the front moves through the first two layers, and then calculates that the thaw index required to penetrate the third layer. In this test case the surface thawing index required to penetrate the third layer exceeds the actual index based on the input environmental parameters. At this point an iteration process is initiated to find the depth within the third layer at which the input and calculated indexes are similar. During the iteration process, the input index (XINDEX) and calculated indexes (SUMIND) are displayed (see Figure 6). Once these two numbers are approximately equal, the screen is again cleared by the program and a similar calculation sequence is undertaken to find the depth of maximum freeze. These two calculations completed, the results are displayed on the screen as shown in Figure 7.

```
          ENVIRONMENTAL PARAMETERS ARE STORED
            FOR THE FOLLOWING LOCATIONS
              1   FAIRBANKS        7   PRUDHOE+BARROW
              2   ANCHORAGE        8   BETHEL
              3   JUNEAU+KODIAK    9   KOTZEBUE
              4   NOME             10  GLENNALLEN
              5   TOK              11  FT. YUKON
              6   DELINGHAM        12  USER INPUT

  LOCATION NUMBER    1

1 LOCATION NAME     :FAIRBANKS
2 THAW N FACTOR     : 1.6
3 FREEZE N FACTOR   : .95
4 MEAN ANNUAL TEMP. : 26
5 THAW    DEG. DAYS : 3787
6 FREEZE DEG. DAYS  : 6700
7 THAW SEASON LENG. : 163
8 FREE. SEASON LENG: 202

   INPUT FIRST LETTER OF DESIRED LOCATION (Y FOR FT. YUKON)
OR USE CURSOR CONTROL KEYS TO MOVE CURSOR AND CHANGE DATA
(TYPE S FOR SOIL DATA, R TO RUN PROGRAM, L FOR A NEW SCREEN)
```

FIGURE 1

```
    LAYER NUMBER  1

          MATERIALS AVAILABLE
       1. GRAVEL
       2. SAND
       3. SILT
       4. ASPHALT
       5. CONCRETE
       6. INSULATION
       7. USER MATERIAL

 NUMBER OF LAYERS                  :9
 MATERIAL NUMBER                   :4
 THICKNESS OF LAYER (FT)           : 0.2
 DENSITY OF LAYER (LB/FT^3)        :138
 % MOISTURE                        : 0
 HEAT CAP. (BTU/FT^3-DEG F)        :28.0
 CONDUCTIVITY (BTU/FT-HR-DEG F):0.86
 LATENT HEAT (BTU/FT^3)            :   0

INPUT LAYER# FOR NEW LAYER OR MOVE CURSOR AND CHANGE DATA
INPUT  AN L FOR LOCATION DATA, AN R TO RUN THE DATA
```

FIGURE 2

```
    LAYER NUMBER  1

          MATERIALS AVAILABLE
        1. GRAVEL
        2. SAND
        3. SILT
        4. ASPHALT
        5. CONCRETE
        6. INSULATION
        7. USER MATERIAL

 NUMBER OF LAYERS                  :3
 MATERIAL NUMBER                   :4
 THICKNESS OF LAYER (FT)           : 0.2
 DENSITY OF LAYER (LB/FT^3)        :138
 % MOISTURE                        : 0
 HEAT CAP. (BTU/FT^3-DEG F)        :28.0
 CONDUCTIVITY (BTU/FT-HR-DEG F) :0.86
 LATENT HEAT (BTU/FT^3)            :   0

INPUT LAYER# FOR NEW LAYER OR MOVE CURSOR AND CHANGE DATA
INPUT  AN L FOR LOCATION DATA, AN R TO RUN THE DATA
```

FIGURE 3

```
   LAYER NUMBER  2

         MATERIALS AVAILABLE
      1. GRAVEL
      2. SAND
      3. SILT
      4. ASPHALT
      5. CONCRETE
      6. INSULATION
      7. USER MATERIAL

 NUMBER OF LAYERS                  :3
 MATERIAL NUMBER                   :1
 THICKNESS OF LAYER (FT)           : 4.0
 DENSITY OF LAYER (LB/FT^3)        :130
 % MOISTURE                        : 3
 HEAT CAP. (BTU/FT^3-DEG F)        :24.5
 CONDUCTIVITY (BTU/FT-HR-DEG F):0.42
 LATENT HEAT (BTU/FT^3)            : 468

INPUT LAYER# FOR NEW LAYER OR MOVE CURSOR AND CHANGE DATA
INPUT  AN L FOR LOCATION DATA, AN R TO RUN THE DATA
```

FIGURE 4

```
    LAYER NUMBER  3

          MATERIALS AVAILABLE
       1. GRAVEL
       2. SAND
       3. SILT
       4. ASPHALT
       5. CONCRETE
       6. INSULATION
       7. USER MATERIAL

 NUMBER OF LAYERS                  :3
 MATERIAL NUMBER                   :1
 THICKNESS OF LAYER (FT)           :10.0
 DENSITY OF LAYER (LB/FT^3)        :130
 % MOISTURE                        : 3
 HEAT CAP. (BTU/FT^3-DEG F)        :24.5
 CONDUCTIVITY (BTU/FT-HR-DEG F):0.42
 LATENT HEAT (BTU/FT^3)            : 468

INPUT LAYER# FOR NEW LAYER OR MOVE CURSOR AND CHANGE DATA
INPUT  AN L FOR LOCATION DATA, AN R TO RUN THE DATA
```

FIGURE 5

```
LAYER NUMBER   1
LAYER NUMBER   2
LAYER NUMBER   3
ITERATION
XINDEX          SUMIND
 6059            9636
 6059            4046
 6059            6544
 6059            5221
 6059            5864
 6059            6199
 6059            6030
 6059            6114
 6059            6072
```

FIGURE 6

ENVIRONMENTAL PARAMETERS

LOCATION	THAW N	FREEZE N	MAT	THAW DEG. DAYS	FREEZE DEG. DAYS	THAW SEA. LEN.	FREEZE SEA. LEN.
FAIRBANK	1.60	0.95	26	3787	6700	163	202

LAYER SOIL PROPERTIES

LAYER #	MATERIAL	DEPTH	DENS.	% MOIS.	HEAT CAP.	COND.	LATENT HEAT
1	ASPHALT	0.2	138.00	0.00	28.00	0.86	0
2	GRAVEL	4.0	130.00	2.50	24.54	0.42	468
3	GRAVEL	10.0	130.00	2.50	24.54	0.42	468

TOTAL THAW DEPTH = 11.3
TOTAL FREEZE DEPTH = 11.8

INPUT L FOR LOCATION, S FOR SOILS, OR Q FOR END

FIGURE 7