REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-GT-13

LEVEE UNDERSEEPAGE SOFTWARE
USER MANUAL AND VALIDATION

by

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Civil Works Work Unit 32274
The following two letters used as part of the number designating technical reports of research published under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program identify the problem area under which the report was prepared:

<table>
<thead>
<tr>
<th>Problem Area</th>
<th>Problem Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS Concrete and Steel Structures</td>
<td>EM Electrical and Mechanical</td>
</tr>
<tr>
<td>GT Geotechnical</td>
<td>EI Environmental Impacts</td>
</tr>
<tr>
<td>HY Hydraulics</td>
<td>OM Operations Management</td>
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<td>CO Coastal</td>
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</tbody>
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COVER PHOTOS:

TOP - Schematic of levee underseepage.
SECOND - Expedient measures for control of high water.
THIRD - Sand boil ringed with sandbags to control adverse effects of underseepage.
BOTTOM - Levee erosion due to a combination of underseepage and through seepage.
A FORTRAN 77 computer program (LEVSEEP) was developed to analyze levee underseepage on IBM PC compatible microcomputers with an 8087 math coprocessor. The software and associated equipment plots cross sections and piezometer data; calculates seepage flow and substratum pressure; analyzes landside berm, river side blanket, cutoff and relief well control measures; and finally, estimates the construction cost of these alternatives. The results of example computer calculations agree favorably with hand solutions. The procedures for berm and relief well analysis reflect the current CE guidance in EM 1110-2-1913. The method of fragments is used for the analysis of cutoff. Riverside blanket analysis are based on procedures presented in the WES Technical Memorandum 3-424. The products are recommended for practical use by Corps' Districts having seepage problems with flood control levees.

(Continued)
6a. NAME OF PERFORMING ORGANIZATION (Continued).
JAYCOR and USAEWES Geotechnical Laboratory

6c. ADDRESS (Continued).
2732 Washington Street, Vicksburg, MS 39180 and 3909 Halls Ferry Road, Vicksburg, MS 39180-6199

18. SUBJECT TERMS (Continued).

<table>
<thead>
<tr>
<th>Berms</th>
<th>Cutoffs</th>
<th>Microcomputer software</th>
<th>Seepage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculations</td>
<td>Levees</td>
<td>Relief wells</td>
<td>Underseepage</td>
</tr>
<tr>
<td>Computer programs</td>
<td>Method of fragments</td>
<td>Riverside blankets</td>
<td>Verification</td>
</tr>
</tbody>
</table>
This study was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Geotechnical (Soil) Problem Area of the REMR Program by JAYCOR for the U.S. Army Engineer Waterways Experiment Station (WES) under Contract No. DACW39-87-M-1524 during the period 3 March through 21 September 1987. The work was performed by part of the Civil Works Work Unit 32274, "Rehabilitation Alternatives to Control Adverse Effects of Levee Underseepage," for which Mr. Hugh M. Taylor, Jr. is the Principal Investigator. Mr. Arthur H. Walz is the REMR Technical Monitor for this study.

The technical work was performed by JAYCOR's Structures Division under the management of Mr. William J. Flathau. The Principal Investigator was Mr. Robert W. Cunny. Dr. Paul F. Mlakar provided valuable technical guidance. Mr. Victor M. Agostinelli, Jr. encoded the computer programs, wrote the instructions for their use, and made the computer example computations. In earlier phases of the study, Mr. Walter C. Sherman assisted with the cutoff analysis, and Mr. Woodland G. Shockley assisted with the relief well analysis. This report was originally typed and copied by Mrs. Caroline P. Cummins with the assistance of Ms. Emma C. Young.

This study was under the direct supervision of Mr. G. Britt Mitchell, the Problem Area Leader, Soils Mechanics Branch (SMB), Soil and Rock Mechanics Division (SRMD), Geotechnical Laboratory (GL). Mr. Taylor, Jr., was also the Contracting Officer's Representative from WES during the conduct of the study and publication of the report. He also incorporated the review comments and reorganized and consolidated the two JAYCOR reports of validation and user manual into the present report. General supervision was provided by Dr. Don C. Banks, Chief, SRMD, and Dr. William F. Marcuson III, Chief, GL. The report was edited by Ms. Odell F. Allen, Information Management Division, Information Technology Laboratory.

The REMR Coordinator at the Directorate of Research and Development HQUSACE, was Mr. Jesse A. Pfeiffer, Jr. Members of the REMR Overview Committee in HQUSACE were Mr. James E. Crews and Dr. Tony C. Liu. The REMR Program Manager is Mr. William F. McCleese.

Commander and Director of WES during the preparation and publication of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREFACE</td>
<td>1</td>
</tr>
<tr>
<td>CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT</td>
<td>4</td>
</tr>
<tr>
<td>PART I: INTRODUCTION</td>
<td>5</td>
</tr>
<tr>
<td>PART II: GENERAL COMMENTS</td>
<td>8</td>
</tr>
<tr>
<td>PART III: PROGRAM EXECUTION</td>
<td>9</td>
</tr>
<tr>
<td>Cross Section</td>
<td>11</td>
</tr>
<tr>
<td>Geotechnical Information</td>
<td>11</td>
</tr>
<tr>
<td>Piezometer Locations</td>
<td>11</td>
</tr>
<tr>
<td>Piezometer Readings</td>
<td>11</td>
</tr>
<tr>
<td>Costs</td>
<td>12</td>
</tr>
<tr>
<td>PART IV: GRADIENT AND SEEPAGE CALCULATIONS</td>
<td>13</td>
</tr>
<tr>
<td>Initial Conditions</td>
<td>13</td>
</tr>
<tr>
<td>Piezometer Data</td>
<td>13</td>
</tr>
<tr>
<td>PZ Plot</td>
<td>13</td>
</tr>
<tr>
<td>PART V: CONTROL MEASURES AND COSTS</td>
<td>14</td>
</tr>
<tr>
<td>Berm</td>
<td>14</td>
</tr>
<tr>
<td>Riverside Blanket</td>
<td>14</td>
</tr>
<tr>
<td>Cutoff</td>
<td>15</td>
</tr>
<tr>
<td>Relief Well</td>
<td>15</td>
</tr>
<tr>
<td>Cost Summary</td>
<td>15</td>
</tr>
<tr>
<td>PART VI: DBASE ACCESS</td>
<td>16</td>
</tr>
<tr>
<td>PART VII: SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS</td>
<td>17</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>18</td>
</tr>
<tr>
<td>APPENDIX A: NOTATIONS</td>
<td>A1</td>
</tr>
<tr>
<td>APPENDIX B: EXAMPLE PROBLEMS</td>
<td>B1</td>
</tr>
<tr>
<td>Computer Output Cross Section 5 Using Keyboard Input, All Control Measures and Cost Summary</td>
<td>B2</td>
</tr>
<tr>
<td>Computer Output Cross Section 6 Using Existing Data Files, Relief Well Analysis</td>
<td>B42</td>
</tr>
<tr>
<td>Computer Output Cross Section 7 Using Existing Data Files, Rock Island Example</td>
<td>B54</td>
</tr>
<tr>
<td>APPENDIX C: VALIDATION</td>
<td>C1</td>
</tr>
<tr>
<td>APPENDIX D: DEFAULT UNIT COSTS</td>
<td>D1</td>
</tr>
<tr>
<td>APPENDIX E: HAND CALCULATIONS AND COMPUTER PRINTOUTS</td>
<td>E1</td>
</tr>
<tr>
<td>Cross Section 1</td>
<td>E2</td>
</tr>
<tr>
<td>Cross Section 2</td>
<td>E27</td>
</tr>
<tr>
<td>Cross Section 3</td>
<td>E56</td>
</tr>
<tr>
<td>Cross Section 4</td>
<td>E95</td>
</tr>
<tr>
<td>Cross Section 5</td>
<td>E126</td>
</tr>
</tbody>
</table>
Cross Section 6...................................................... E167
Cross Section 7................................................... E182

COMPUTER DISKS ATTACHED
Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>cubic yards</td>
<td>0.7645549</td>
<td>cubic metres</td>
</tr>
<tr>
<td>feet</td>
<td>0.3048</td>
<td>metres</td>
</tr>
<tr>
<td>gallons (US liquid) per minute</td>
<td>0.006309</td>
<td>cubic metre per second</td>
</tr>
<tr>
<td>inches</td>
<td>2.54</td>
<td>centimetres</td>
</tr>
<tr>
<td>pounds (mass) per cubic foot</td>
<td>16.01846</td>
<td>kilograms per cubic metre</td>
</tr>
<tr>
<td>square feet per second</td>
<td>0.09290304</td>
<td>square metres per second</td>
</tr>
</tbody>
</table>
LEVEE UNDERSEEPAGE SOFTWARE USER MANUAL
AND VALIDATION

PART I: INTRODUCTION

1. Levee underseepage has been identified by the Corps of Engineers field personnel to be one of the high-priority soils-related problems being addressed in the Repair, Evaluation, Maintenance and Rehabilitation (REMR) Research Program (Scanlon et al. 1983). Seepage control measures include landside berms, riverside blankets, cutoffs, and relief wells. The technical guidance concerning these measures appears in Engineer Manual (EM) 1110-2-1913 (1978) and US Army Engineer Waterways Experiment Station (WES) (1956). Early in 1985, Corps' field personnel indicated a specific need for a user-friendly, microcomputer-based analytic tool for use in analyzing these control measures.

2. On 26 June 1985, a contract was awarded to JAYCOR to develop levee underseepage analysis computer programs in accordance with the following tasks:
   a. Adopt an existing plot program for a mainframe computer to a personal computer.
   b. Extend the program to have additional plotting and calculating capability for underseepage analysis.
   c. Develop a program capable of calculating the effect of various control measures on levee underseepage performance.
   d. Develop a data base to store graphic and tabular information generated by the programs.
   e. Develop a program to compute construction quantities required for landside berms, riverside blankets, and cutoff control measures and calculate costs for each measure.
   f. Validate the programs with hand calculations and produce a user's guide for the programs.

The work described above was completed and reported to the WES (Cunny, Mlakar, and Agostinelli 1985).

3. In 1986 the need to expand the Levee Underseepage Analysis Program to include the analysis of relief wells for underseepage control was recognized. On 28 July 1986, a contract was awarded to JAYCOR to develop a relief well analysis computer program in accordance with the following:
   a. Develop procedures for analysis of infinite relief well systems for levee underseepage control.
b. Incorporate the procedures for relief well analysis into the programs CONTROL and COST of the Levee Underseepage Analysis Program (Cunny, Mlakar, and Agostinelli 1985).

c. Validate the program with hand calculations and produce a report of validation and a user's guide for the program.

The work described above was completed and reported (Shockley et al. 1986).

4. In 1987 the WES authorized JAYCOR to combine the results of the previous 2 years work and make the following modifications and additions:

   a. Input into a common file all general data for analysis of each of the control measures.

   b. Rewrite the graphical output to use Micrographics Compatibility System library of subroutines (WES 1979) in lieu of the Micro TEMPLATE library.

   c. Add an example problem representing a case history from the US Army Engineer District, Rock Island and add procedures used by the District for calculating berm dimensions.

In addition, the following items of an editorial and/or technical nature have been incorporated in this work:

   a. The program has been completely reorganized to make solutions more direct and to improve the program's user friendliness.

   b. Plot routines have been added for berms and blankets.

   c. An option for calculating the transformed permeability of the top stratum has been added.

   d. An option to calculate allowable gradients based on submerged unit weight and factor of safety has been added.

   e. The minimum berm thickness has been changed from 6.2 to 5.0 ft.*

   f. A default value of $3.75 for unit cost of a sand berm has been added.

   g. A single page summary of cost for various control measures for any one cross section has been added.

   h. The total depth of cutoffs and relief wells has been corrected to include actual thickness rather than transformed thickness of the top stratum.

   i. The procedure for calculating the thickness of a shortened berm was corrected to include a modified equation for uplift pressure.

   j. The procedure for calculating entrance and exit distances was corrected for relief well analysis for the case of no top stratum.

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.
k. Printed output is limited to significant figures, and wrap-arounds have been eliminated.

1. A routine has been added to determine that the thickness of a berm will not be so great that the berm slope will not intersect the landside levee slope.

5. The computer program developed in this effort, LEVSEEP, is written for the IBM PC and compatible computers using the MS DOS operating system (Microsoft Corporation 1983). The language used is Microsoft FORTRAN 77 (Version 3.31) (Microsoft Corporation 1984). Graphical displays are created using Micrographics Compatibility System (Version 3.1) library of subroutines (WES 1979). The key factors describing seepage flow and substratum hydrostatic pressures calculated by the program are saved in files which are compatible with the DBASE II or III software (Ashton-Tate 1984).

6. This report is a manual containing detailed instructions for the use of the program LEVSEEP. Parts II and III offer general comments and rules, respectively, for effective use of the program capabilities. Instructions for input data, gradient and seepage calculations, and control measures and cost options are included in Parts IV and V. Part VI provides the steps to access the output files through DBASE, and Part VII gives a summary of the report. Appendix A documents the notation. Three example problems illustrating the use of these options are included in Appendix B. Appendix C describes the analytic procedures for calculating levee underseepage and its control, and it demonstrates example computer solutions and hand computations. Default unit costs are given in Appendix D. A comparison of hand calculations and computer calculations are given in Appendix E.
PART II: GENERAL COMMENTS

7. In order to facilitate the analysis for control of levee underseepage, this software emphasizes menu-driven control, individual displays of results, summary displays, default values, and graphical output wherever necessary. In addition, the program has been structured to allow for re-entry of the data. Calculations may be done in any order; additional input may sometimes be prompted for further computations.

8. Attention was given to include as much identification as possible on both graphical and textual output displays to avoid confusion in identifying results. Graphical output may be sent to the screen, a Hewlett-Packard plotter, or a printer.

9. Notations used in this report are consistent with that in EM 1110-2-1913 (1978) and are shown in Appendix A. Supplemental computer notations are also listed in Appendix A.
PART III: PROGRAM EXECUTION

10. General guidance for program execution is as follows:

a. LEVSEEP operates with four principal menus with appropriate options as follows:

(1) Levee Underseepage Main Menu.
   (a) Set up system for plotter.
   (b) Input data.
   (c) Gradient and seepage calculations.
   (d) Control measure and cost.
   (e) End program.

(2) Input Data Menu.
   (a) Cross section.
   (b) Geotechnical properties.
   (c) Piezometer locations.
   (d) Piezometer and pool readings.
   (e) Control measure unit costs.
   (f) End input.

(3) Gradient and Seepage Calculations Menu.
   (a) Initial conditions.
   (b) From piezometer data.
   (c) Piezometer plot.
   (d) End calculations.

(4) Control Measure and Cost Menu.
   (a) Berm.
   (b) Riverside blanket.
   (c) Cutoff.
   (d) Relief well.
   (e) Cost summary.
   (f) End.

b. Additional menus, many of which are illustrated in Appendix B, are used when appropriate options are called. However, additional menus not shown in Appendix B will come in if an appropriate response is given to a programmed question. For example, if the response is "Y" to the question "Calculate \( z_{bl} \), \( k_{bl} \), \( z_{br} \), \( k_{br} \), \( z_t \), and \( z_1 \)?", an additional menu and library of information come into play for the calculation of the transformed thickness and permeability of the top stratum.
c. For menu selection, enter only the number of the choice.

d. For question prompts, enter only 'Y' or 'N'; capital letters are required.

e. To select default values, press <RETURN>; a <RETURN> without a default value will result in an undefined value unless input is made from keyboard.

f. All output is paused until a key is pressed. Graphical output concludes at the beep.

g. File names may be up to 25 characters (allows for path and/or drive names).

h. If a file already exists, saving to that file will overwrite existing data.

i. If a file is not found, an error message is printed and control goes back to the program.

j. Always run Initial Conditions Option under the Gradient and Seepage Calculations Menu before running berm, blanket, cutoff, or relief well control measures.

k. On execution, the default plotter environment is 1,200 baud and serial port 1. Thus, the DOS command "MODE COM1 : 1,200, N, 8, 2, P" should be executed before LEVSEEPE and the plotter switches should be set to 1,200 baud. Other serial ports and baud rates may be selected through option "0" of the Levee Underseepage Main Menu. In this case, the corresponding MODE command must be executed as described in the DOS manual, and the switches must be set appropriately as described in the plotter manual before executing LEVSEEPE.

11. Each of the calculation options require certain input. The following tabulation shows which inputs are required and which are optional for Gradient and Seepage Calculations and Control Measures and Cost Menus:

<table>
<thead>
<tr>
<th>Option</th>
<th>Cross Section</th>
<th>Geotechnical Properties</th>
<th>Piezometer Locations and Readings</th>
<th>Control Measure and Cost Menu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient and Seepage Calculations Menu</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Initial conditions</td>
<td>Optional</td>
<td>Required</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2. From piezometer data</td>
<td>Optional</td>
<td>Required</td>
<td>Required</td>
<td>NA</td>
</tr>
<tr>
<td>3. Piezometer Plot</td>
<td>Required</td>
<td>Optional</td>
<td>Required</td>
<td>NA</td>
</tr>
<tr>
<td>Control Measure and Cost Menu</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Berm</td>
<td>Optional</td>
<td>Required</td>
<td>NA</td>
<td>Optional</td>
</tr>
<tr>
<td>2. Riverside blanket</td>
<td>Optional</td>
<td>Required</td>
<td>NA</td>
<td>Optional</td>
</tr>
<tr>
<td>3. Cutoff</td>
<td>Optional</td>
<td>Required</td>
<td>NA</td>
<td>Optional</td>
</tr>
<tr>
<td>4. Relief well</td>
<td>Optional</td>
<td>Required</td>
<td>NA</td>
<td>Optional</td>
</tr>
</tbody>
</table>
If required input is not present, the program will prompt the user to supply it.

**Cross Section**

12. When inputting cross-section points landward of the levee, values are assumed to be less than riverward values. Commonly, the center line of the levee is taken to be zero so that negative values would represent points landward of the center line and positive values riverward.

**Geotechnical Information**

13. When entering geotechnical input, observe the following rules:
   a. All numerical input must be less than or equal 10 characters.
   b. If the length of the landward top stratum, \( L_3 \), is infinite, enter 'INFINITE.'
   c. If a default value is not listed, \(<\text{RETURN}>\) will cause the value to remain undefined and may cause unpredictable results in calculations requiring that value.
   d. Special geotechnical input is not required for the cutoff analysis. However this option was left on the menu for potential program expansion.
   e. By choosing to explicitly enter \( k_b \) when calculating \( z_{bl} \), \( z_{br} \), \( z_t \), \( z_1 \), \( k_{bl} \), and \( k_{br} \), the default choice of \( k_b \) is disabled and the user is prompted for \( k_b \).

**Piezometer Locations**

14. The piezometer location input is used for one-time entry of piezometer data. The same piezometer information may be used in conjunction with any number of files with piezometer and pool readings.

**Piezometer Readings**

15. Piezometer readings and pool readings are input with their corresponding data. Each piezometer reading is identified by the piezometer number. This name must correspond exactly to the piezometer name entered under piezometer locations.
Costs

16. Prompts asking for cost input will default to the indicated cost. If no default, the user, by hitting <RETURN>, will cause the cost to remain undefined as in the pervious berm prompt or cause the computer to prompt the user again for some value as in the relief well costs. The user is prompted for the cutoff unit cost as a function of depth. The last unit cost corresponds to all depths beyond the previous one. After costs have been given by the user, they may be saved to a file for future program execution. These costs may be retrieved from this file instead of entering them from the keyboard again.
PART IV: GRADIENT AND SEEPAGE CALCULATIONS

Initial Conditions

17. This option only prompts the user for the graphics device driver if a cross section is present and for the choice of whether to save output to a DBASE compatible file.

Piezometer Data

18. Initially, the user is asked to choose from the displayed list of dates for which piezometer and pool readings were entered. After a date is chosen, seepage calculations are made based on the piezometer readings. All other prompts are the same as those for the Initial Conditions Option.

PZ Plot

19. This option produces a plot of piezometer and pool readings. The user is prompted for one of the listed dates for which readings were entered and for the graphics output driver.
PART V: CONTROL MEASURES AND COSTS

20. The presence of control measure unit costs is checked so that the user may input unit costs before going through control measure calculations. In addition, choices of graphics output drivers and whether to save data to a DBASE accessible file are necessary.

Berm

21. The following prompts occur for berms:
   a. Minimum and maximum berm widths must be chosen by the user. Default widths are given.
   b. When a creep ratio is needed for standard Corps calculations, the user is asked for the soil type with a default creep ratio of 8.5 for that of very fine sand or silt.
   c. If the berm fails the thickness check, a message is printed indicating that the berm failed.
   d. Refer to blanket responses if a blanket is calculated.
   e. If a Rock Island berm option is selected, the user is asked for a creep ratio with a default value of 10.

Riverside Blanket

22. When calculating blankets, the user is asked for the following responses:
   a. In order to determine blanket type, the user is asked to indicate the presence of a borrow pit.
   b. The value of $x_T$ is checked against $L_1$. If $x_T$ or $L_B$ is less than the distance to the river, calculations are valid for this case and the calculations will continue.
   c. If a borrow pit is indicated, a value of $z_{br}$ must be chosen for the borrow pit.
   d. In the case of no natural riverside top stratum, one of two blankets may be calculated: (1) uniform thickness or (2) triangular section.
   e. At some point in the calculations, the user is prompted for some combination of $L_B$, $k_B$, or $k_{bb}$ and $z_B$ or $z_{bb}$ input. When given a choice, the user enters the menu option of the variable or variables that he would input. The others are calculated when possible.
When choosing the input $L_B$, $k_b$, $k_{bB}$, $z_B$, or $z_{Bb}$, trial values may be entered in order to observe the effects on the other results. Having decided on a value, the user enters <RETURN> and proceeds to enter his choice for the remainder of the calculations.

**Cutoff**

23. Only the $d_c/d$ ratio is required from user input.

**Relief Well**

24. If the Relief Well Option is chosen, the user is asked for the number of layers in the pervious foundations. If a multilayer system is present, the horizontal permeability and thickness are prompted for each layer. If only one layer is indicated, those values are retrieved from the geotechnical input.

**Cost Summary**

25. This option is simply a summary sheet of cost calculations. It has no inputs.
PART VI: DBASE ACCESS

26. To access any of the output files, they must first be labeled with the extension .TXT. DBASE is then entered as described in the DBASE Manual. First, a data base must be set up using the DBASE command CREATE. The field widths used are as follows:

- PROJECT, C, 30
- STATION, C, 10
- DATE, C, 10
- TIME, C, 10
- ID, C, 10
- XI, C, 10
- X3, C, 10
- M, C, 10
- I, C, 10
- QS, C, 10
- H, C, 10
- VB, C, 10
- VRB, C, 10
- DC, C, 10
- IAVG, C, 10
- IE, C, 10
- P, C, 10
- ASEL, C, 10
- WBAR, C, 10
- QW, C, 10
- CWS, C, 10

Next, the user must append the files to the data base by using the APPEND command as follows:

APPEND FROM <OUTPUT FILE> SDF DELIMITED

Each output file must be individually appended to the data base.
PART VII: SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

27. A computer program has been developed to analyze levee underseepage on IBM PC and compatible microcomputers. The software and associated equipment plot cross sections and piezometer data; calculate seepage flow and substratum pressure; analyze landside berm, riverside blanket, cutoff and relief well control measures; and estimate the construction cost of these alternatives. The results of example computer calculations agree favorably with hand solutions. The products are recommended for practical use by Corps' Districts having seepage problems with flood control levees. It is recommended that future work includes development of an economical procedure for the analysis of cutoffs which is reasonably accurate in all cases of practical interest. Also, the potential economies of using combinations of control measures should be studied.
REFERENCES


US Army Engineer Division, Huntsville. 1986. "Corps of Engineers Training Course, Seepage Analysis and Control for Dams," prepared for US Army Engineer Waterways Experiment Station, Vicksburg, MS.

US Army Engineer Waterways Experiment Station. 1956. "Investigation of Underseepage and Its Control, Lower Mississippi River Levees, Volume I," Technical Memorandum 3-424, prepared for Mississippi River Commission, Vicksburg, MS.


APPENDIX A: NOTATIONS

\( a \) Well spacing

\( a_{sel} \) Selected well spacing

\( c_B \) Constant for artificial riverside blanket where \( c_B = \left( \frac{k_B}{k_f z_B D} \right)^{1/2} \)

\( c_{Bb} \) Constant for riverside blanket and natural riverside top stratum

\[
\text{where } c_{Bb} = \left( \frac{k_{Bb}}{k_f z_{Bb} D} \right)^{1/2}
\]

\( c_{bl} \) Constant for natural landside top stratum where \( c_{bl} = \left( \frac{k_{bl}}{k_f z_{bl} D} \right)^{1/2} \)

\( c_{br} \) Constant for natural riverside top stratum where \( c_{br} = \left( \frac{k_{br}}{k_f z_{br} D} \right)^{1/2} \)

\( C_w \) Lane's creep ratio

\( d \) Thickness of layered pervious substratum

\( d_n \) Thickness of individual layer in pervious substratum

\( d_c \) Depth of cutoff

\( d' \) Transformed depth of cutoff

\( D \) Thickness of single layered pervious foundation

\( D, d' \) Transformed thickness of pervious substratum

\( D_p \) Inside diameter of well screen and riser pipe

\( f \) Resistance coefficient for flow in pipe

\( F_t \) Transformation factor

\( F_s \) Factor of safety

\( h_a \) Allowable (net) head beneath landside top stratum

\( h_b \) Height of berm intercept on levee landside slope = \( m_1 t / (m_1 - m_2) \)

\( h \) Friction head loss in 100 ft of pipe

\( h_o \) Hydrostatic head beneath top stratum at landside toe of levee without seepage control measures

\( h'_o \) Hydrostatic head beneath top stratum at landside toe of levee with berm

\( H \) Net head on levee, or height of flood stage above average low ground surface or tailwater landward of levee

\( H_{av} \) Gross average head in plane of wells

\( h_e \) Entrance head loss through filter and well screen
He1

Height of well top above tailwater

Hm

Head midway between wells

Hr

Friction head loss in riser pipe

Hs

Friction head loss in well screen

Hw

Total hydraulic head loss in well

Hi

Velocity head loss in well

i

Upward gradient at landside toe, \( h_o/z_t \)

ia

Allowable upward gradient at landside toe of levee for riverside blanket design

icr

Critical gradient through landside top stratum

i1

Allowable upward gradient at landside toe of berm

io

Allowable upward gradient at landside toe of levee

J

Percent reduction in seepage flow beneath levee

k

Coefficient of permeability

kB

Permeability of artificial riverside blanket

kBb

Average combined vertical permeability of riverside natural top stratum and artificial blanket

kf

Permeability of pervious foundation

kfh

Horizontal permeability of pervious stratum

kfV

Vertical permeability of pervious stratum

k

Transformed permeability \( (k_{fh} \times k_{fv})^{1/2} \)

kJ

Permeability of landside top stratum

kB1

Permeability of riverside top stratum

kB2

Permeability of individual stratum

khn

Vertical permeability of individual stratum

kvt

Vertical permeability of landside seepage berm

L1

Riverward extent of top stratum measured from riverside levee toe

L2

Base width of levee and impervious berm, if present

L3

Landward extent of top stratum measured from landside levee toe

L4

Extra entrance length for Rock Island berm design = 0.44 D

LB

Width of riverside borrow pit and/or required length of artificial riverside blanket

LBq

Width of riverside blanket required to reduce seepage

m1

Average landside slope of levee

m2

Berm slope

m3

Slope at berm toe, or toe of triangular riverside blanket
m₄ Average riverside slope of levee
m₅ Slope of triangular riverside blanket
M Slope of hydraulic grade line
N Number of layers in pervious foundation
P Effective penetration of well screen into pervious foundation
Qₛ Total amount of seepage passing beneath levee per 100 ft of levee station
Qₗᵢ Well discharge
Qₜᵢ Desired well discharge to achieve flow reduction J
rₑ Effective radius of well
Rₑ Reynolds number
s Distance from the landside toe of the levee to the point of effective seepage entry, x₁ + L₂
t Required thickness of landside seepage berm at toe of levee
V₉ Volume of berm per 100 ft of levee station
Vᵣ₉ᵦ Volume of riverside blanket per 100 ft of levee station
wₑ Actual length of well screen in pervious foundation
x₁ Effective length of riverside blanket
x₃ Distance from landside levee toe to effective seepage exit
xᵣᵦ Required effective length of riverside blanket to reduce hydrostatic pressure
xᵣᵦᵦ Required effective length of riverside blanket to reduce seepage
Xᵦ Width of impervious berm
Xₛ Width of semipervious berm
Xₛ≧ Width of sand berm
Xᵦᵦᵦ Width of pervious berm with collector pipe
z Total thickness of top stratum
z₉ Thickness of artificial riverside blanket
zᵦᵦᵦ Total effective thickness of natural and artificial riverside top stratum
zᵦᵦ₁ Transformed thickness of landside top stratum
zᵦᵦᵦᵦ Transformed thickness of riverside top stratum
z₁ Total thickness of landside top stratum
z₁ᵦᵦ Thicknesses of individual layers (n layers) in landside top strata
zᵦᵦᵦᵦᵦ Total thickness of riverside top strata
zᵦᵦᵦᵦᵦᵦ Thicknesses of individual layers (n layers) in riverside top strata
Total thicknesses of riverside top strata

Thicknesses of individual layers (n layers) in riverside top strata

Critical thickness of top stratum

Shape factor of generalized cross section of the levee and foundation

Submerged unit weight of landside top stratum soil

Coefficient of pipe roughness

Average uplift factor

Midpoint uplift factor

Viscosity of water at a given temperature

Form factor used with method of fragments

SUPPLEMENTAL COMPUTER NOTATIONS

BF Backfill
DD Transformed thickness of previous substratum
DRP Drilling through previous foundation cost
DRT Drilling through top stratum cost
FL Filter cost
FSB Factor of safety for berm analysis
FSW Factor of safety for well analysis
IOB Allowable gradient at landside levee toe for berm analysis
LTE Landside toe elevation
LTO Landside toe offset
M3B Slope at berm toe
M3R Slope at triangular riverside blanket toe
RP Risen pipe cost
RTO Riverside toe offset
SUBWT Submerged unit weight of top stratum
WC Well cover cost
WD Well development cost
WS Well screen cost
$ Shape factor
APPENDIX B: EXAMPLE PROBLEMS

This appendix contains sample executions of LEVSEEP on cross-section examples 5, 6, and 7. They are presented to guide initial and infrequent users in analyzing practical seepage problems. The example run for cross section 5 assumes that no data files exist, and the runs for cross sections 6 and 7 use data files that have been entered previously. Selected plots are included to illustrate the capability of the plot routine.
Computer Output Cross Section 5
Using Keyboard Input

All Control Measures and Cost Summary
Cross Section 5, Main Menu, Input Data, Cross Section

2J 09-21-87

LEVEE UNDERSEEPAGE MAIN MENU
-------------------------------------

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ===> 1
2J 09-21-87

INPUT DATA MENU
----------------

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ===> 1
2J 09-21-87

CROSS-SECTION INPUT
-------------------

IS CROSS-SECTION IN A DATA FILE? (Y/N) N
ENTER # LINES IN CROSS-SECTION ===> 5
2J 09-21-87

LINE #    1
-----------

ENTER # OF POINTS FOR LINE (X,Y=1 FT.) ===> 14
ENTER POINTS (X,Y FORMAT) LOOKING LEFT TO RIGHT:
LANDSIDE TO THE LEFT AND RIVERSIDE TO THE RIGHT:
-1600,164.5
-400,164.5
-390,168
-125,178
-10,201.3
10,201.3
110,170
190,167.5
200,164.5
400,164.5
401,135
Cross Section 5, Input Data, Cross Section

1200,157
1201,164.5
1600,164.5
2J 09-21-87

LINE # 2

ENTER # OF POINTS FOR LINE (X,Y=1 PT.) ==> 5
ENTER POINTS (X,Y FORMAT) LOOKING LEFT TO RIGHT
LANGSIDE TO THE LEFT AND RIVERSIDE TO THE RIGHT
-800,153
200,153
201,151
400,151
401,157
2J 09-21-87

LINE # 3

ENTER # OF POINTS FOR LINE (X,Y=1 PT.) ==> 3
ENTER POINTS (X,Y FORMAT) LOOKING LEFT TO RIGHT
LANGSIDE TO THE LEFT AND RIVERSIDE TO THE RIGHT
1200,157
1201,151
1600,151
2J 09-21-87

LINE # 4

ENTER # OF POINTS FOR LINE (X,Y=1 PT.) ==> 2
ENTER POINTS (X,Y FORMAT) LOOKING LEFT TO RIGHT
LANGSIDE TO THE LEFT AND RIVERSIDE TO THE RIGHT
-800,164.5
-800,113
2J 09-21-87

LINE # 5

ENTER # OF POINTS FOR LINE (X,Y=1 PT.) ==> 2
ENTER POINTS (X,Y FORMAT) LOOKING LEFT TO RIGHT
LANGSIDE TO THE LEFT AND RIVERSIDE TO THE RIGHT
-1600,113
1600,113

WANT TO SAVE CROSS-SECTION POINTS? (Y/N) Y
CROSS-SECTION FILE NAME (MAX=25 CHRS) ==> CROSS
### CROSS-SECTION

#### # OF LINES = 5

#### # OF POINTS IN LINE 1 = 14

<table>
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<tr>
<th>X</th>
<th>Y</th>
</tr>
</thead>
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</tr>
<tr>
<td>-400.0,</td>
<td>164.5</td>
</tr>
<tr>
<td>-390.0,</td>
<td>168.0</td>
</tr>
<tr>
<td>-125.0,</td>
<td>178.0</td>
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<tr>
<td>10.0,</td>
<td>201.3</td>
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<tr>
<td>110.0,</td>
<td>170.0</td>
</tr>
<tr>
<td>190.0,</td>
<td>167.5</td>
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<tr>
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<td>164.5</td>
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<tr>
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<td>157.0</td>
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<td>1201.0,</td>
<td>164.5</td>
</tr>
<tr>
<td>1600.0,</td>
<td>164.5</td>
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</table>

#### # OF POINTS IN LINE 2 = 5

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<td>153.0</td>
</tr>
<tr>
<td>201.0,</td>
<td>151.0</td>
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<tr>
<td>400.0,</td>
<td>151.0</td>
</tr>
<tr>
<td>401.0,</td>
<td>157.0</td>
</tr>
</tbody>
</table>

#### # OF POINTS IN LINE 3 = 3

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<th>Y</th>
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</thead>
<tbody>
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<td>157.0</td>
</tr>
<tr>
<td>1201.0,</td>
<td>151.0</td>
</tr>
<tr>
<td>1600.0,</td>
<td>151.0</td>
</tr>
</tbody>
</table>
Cross Section 5, Input Data, Cross Section

# OF POINTS IN LINE 4 = 2

\[
\begin{array}{cc}
X & Y \\
-800.0 & 164.5 \\
-800.0 & 113.0 \\
\end{array}
\]

# OF POINTS IN LINE 5 = 2

\[
\begin{array}{cc}
X & Y \\
-1600.0 & 113.0 \\
1600.0 & 113.0 \\
\end{array}
\]

2J 09-21-87

DO YOU WANT TO SEE GRAPH? (Y/N) Y

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==> 2

COMPUTER WORKING....
Cross Section 5, Input Data, Cross Section

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE === 3
2J 09-21-87

INPUT DATA MENU

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE === 2
Cross Section 5, Input Data, Geotech Properties

2J 09-21-87

GEOTECH PROPERTIES INPUT

DOES FILE WITH GEOTECH PROPERTIES EXIST? (Y/N) N

2J 09-21-87

IF DATA IS INFINITE, ENTER "INFINITE"

PROJECT NAME (MAX=30 CHRS.) ===>
PROGRAM DEVELOPMENT

STATION NUMBER (MAX=10 CHRS.) ===>
X-SECT.5

LTE : LANDSIDE TOE ELEVATION (FT) ===>
164.5

LTO : LANDSIDE TOE OFFSET (FT) ===>
400

RTO : RIVERSIDE TOE OFFSET (FT) ===>
200

H : NET HEAD ON LEVEE (FT) ===>
29.8

L1 : RIVERWARD EXTENT OF TOP STRATUM MEASURED FROM
RIVERSIDE LEVEE TOE (FT) ===>
200

L3 : LANDWARD EXTENT OF TOP STRATUM MEASURED FROM
LANDSIDE LEVEE TOE (FT) ===>
400

ENTRANCE (OPEN/BLOCKED) ===>
OPEN

EXIT (OPEN/BLOCKED) ===>
BLOCKED

SUBWT : TOP STRATUM SUBMERGED WEIGHT (LBS/CU FT)
(DEFAULT=50) ===>

2J 09-21-87

CALCULATE KF, D, AND DD? (Y/N) N

KF : AVERAGE HORIZONTAL COEFFICIENT OF PERMEABILITY
(CM/S) (DEFAULT=0.125) ===>
0.25

DD : PERVIOUS SUBSTRATUM EFFECTIVE THICKNESS (FT) ===>
40

D : PERVIOUS SUBSTRATUM ACTUAL DEPTH (FT) ===>
40

2J 09-21-87

CALCULATE ZBL, KBL, ZBR, KBR, ZT, AND ZL? (Y/N) N

ZBL : EFFECTIVE THICKNESS OF LANDSIDE
TOP STRATUM (FT) ===>
1105

KBL : LANDSIDE TOP STRATUM PERMEABILITY (CM/S) ===>
0.00015

ZBR : EFFECTIVE THICKNESS OF RIVERSIDE
TOP STRATUM (FT) ===>
13.5

KBR : RIVERSIDE TOP STRATUM PERMEABILITY (CM/S) ===>
0.00002

ZT : EFFECTIVE THICKNESS FOR UPLIFT (FT) ===>
11.5

ZL : TOP STRATUM THICKNESS (FT) ===>
14
Cross Section 5, Input Data, Control Measure

2J 09-21-87 10:13:35

CONTROL MEASURE INPUT
---------------------
1. BERM INPUT
2. BLANKET INPUT
3. CUTOFF INPUT
4. WELL INPUT
5. END OF CONTROL MEASURE INPUT

ENTER NUMBER OF CHOICE ===> 1
2J 09-21-87 10:15:34

BERM INPUT
----------

DO YOU WANT TO CALCULATE I08? (Y/N) N

I08 : LEVEE LANDSIDE TOE ALLOWABLE UPWARD GRADIENT
(DEFAULT=0.3) ===> 
I1 : BERM LANDSIDE TOE ALLOWABLE UPWARD GRADIENT
(DEFAULT=0.8) ===> 
M1 : LANDSIDE SLOPE OF LEVEE ===> 0.076
M3B : SLOPE AT BERM TOE (DEFAULT=0.25) ===> 
2J 09-21-87 10:20:02

CONTROL MEASURE INPUT
---------------------
1. BERM INPUT
2. BLANKET INPUT
3. CUTOFF INPUT
4. WELL INPUT
5. END OF CONTROL MEASURE INPUT

ENTER NUMBER OF CHOICE ===> 2
2J 09-21-87 10:20:09

RIVERSIDE BLANKET INPUT
------------------------

IA : BLANKET LANDSIDE TOE ALLOWABLE UPWARD GRADIENT
(DEFAULT=0.7) ===> 
M3R : SLOPE AT TRIANGULAR RIVERSIDE BLANKET TOE
(DEFAULT=0.25) ===> 
M4 : AVERAGE RIVERSIDE LEVEE SLOPE ===> 0.17
Cross Section 5, Input Data, Control Measure

2J 09-21-87 10:20:24

CONTROL MEASURE INPUT

1. BERM INPUT
2. BLANKET INPUT
3. CUTOFF INPUT
4. WELL INPUT
5. END OF CONTROL MEASURE INPUT

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87 10:20:32

CUTOFF INPUT

NO SPECIAL INPUTS REQUIRED

2J 09-21-87 10:20:37

CONTROL MEASURE INPUT

1. BERM INPUT
2. BLANKET INPUT
3. CUTOFF INPUT
4. WELL INPUT
5. END OF CONTROL MEASURE INPUT

ENTER NUMBER OF CHOICE ===> 4
2J 09-21-87 10:20:43

RELIEF WELL INPUT

DO YOU WANT TO CALCULATE IOW? (Y/N) N

IOW : LEVEE LANDSIDE TIE ALLOWABLE UPWARD GRADIENT
(DEFAULT=0.53) ===>

RW : EFFECTIVE WELL RADIUS (FT)
(DEFAULT=1) ===>

DP : INSIDE DIAMETER OF WELL PIPE (FT)
(DEFAULT=0.67) ===>

RUFE : COEFFICIENT OF PIPE ROUGHNESS
STAINLESS STEEL ......... 0.00005
GALVANIZED STEEL ......... 0.00006
PLASTIC, PVC ......... 0.0001
0.0001

VISCOS : VISCOSITY OF WATER (FT*GAL/SEC)
(DEFAULT=0.0000121) AT 60 F ===>

HELF : WELL TOP HEIGHT ABOVE TAILWATER (FT)
(DEFAULT=0.33) ===>

B10
Cross Section 5, Input Data, Control Measure

2J 09-21-87

CONTROL MEASURE INPUT

1. BERM INPUT
2. BLANKET INPUT
3. CUTTOFF INPUT
4. WELL INPUT
5. END OF CONTROL MEASURE INPUT

ENTER NUMBER OF CHOICE ==> 5

2J 09-21-87

DO YOU WANT TO SAVE THIS LEVEE DATA? (Y/N) N

2J 09-21-87

PROJECT NAME : PROGRAM DEVELOPMENT
STATION : X-SECT.5

GENERAL CONTROL MEASURE INPUT DATA

LTE = 164.5 FT
H  = 29.8 FT
LTO = 400 FT  RTO = 200 FT

L1 = 200 FT  ENTRANCE = OPEN
L3 = 400 FT  EXIT = BLOCKED

D  = 40 FT  DD = 40 FT
ZBL = 11.5 FT  KBL = 0.00015 CM/S
ZBR = 13.5 FT  KBR = 0.00002 CM/S
ZT = 11.5 FT  KF = 0.25 CM/S
ZL = 14 FT

SUBWT = 50. LB/CU FT
Cross Section 5, Input Data, Control Measure

2J 09-21-87  

SUPPLEMENTAL CONTROL MEASURE INPUT DATA

BERM

FSB = UNDEFINED  IA = 0.7
IOB = 0.3  M3R = 0.25
I1 = 0.8  M4 = 0.19
M1 = 0.076
M3B = 0.25

CUTOFF

NO SPECIAL INPUT REQUIRED

FSW = UNDEFINED
IOW = 0.53
RW = 1.0  FT
DP = 0.67  FT
RUSS = 0.000012  GAL/FT/SEC
J = UNDEFINED  %
HEL = 0.33  FT

INPUT DATA MENU

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ===> 3

2J 09-21-87  

PIEZOMETER LOCATION INPUT

PZ LOCATIONS IN A FILE? (Y/N) N

2J 09-21-87  

NUMBER OF PIEZOMETERS (<=50) ===> 5
Cross Section 5, Input Data, Piezometer Location

<table>
<thead>
<tr>
<th>PZ #</th>
<th>PZ NUMBER (MAX=10 CHRS)</th>
<th>PZ STATION (MAX=10 CHRS)</th>
<th>PZ OFFSET (MAX=10 CHRS)</th>
<th>PZ TIP ELEVATION</th>
<th>PZ TOP ELEVATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B-3</td>
<td>38+00</td>
<td>200D/S</td>
<td>140</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>B-4</td>
<td>38+00</td>
<td>200D/S</td>
<td>145</td>
<td>175</td>
</tr>
<tr>
<td>3</td>
<td>B-5</td>
<td>38+00</td>
<td>400D/S</td>
<td>140</td>
<td>165</td>
</tr>
<tr>
<td>4</td>
<td>B-6</td>
<td>38+00</td>
<td>600D/S</td>
<td>135</td>
<td>165</td>
</tr>
<tr>
<td>5</td>
<td>B-7</td>
<td>38+00</td>
<td>985D/S</td>
<td>130</td>
<td>165</td>
</tr>
</tbody>
</table>

2J 09-21-87 10:33:24

WANT TO SAVE PZ LOCATIONS? (Y/N) Y
PZ LOCATION FILE NAME (MAX=25 CHRS) ==> PZLOCST
Cross Section 5, Input Data, Piezometer Location

2J 09-21-87

PIEZOMETER LOCATIONS

# OF PIEZOMETERS = 5

<table>
<thead>
<tr>
<th>PNO</th>
<th>PSTA</th>
<th>POFF</th>
<th>TIPEL</th>
<th>TOPEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-3</td>
<td>38+00</td>
<td>200/H</td>
<td>140.0</td>
<td>200.0</td>
</tr>
<tr>
<td>B-4</td>
<td>38+00</td>
<td>200D/S</td>
<td>145.0</td>
<td>175.0</td>
</tr>
<tr>
<td>B-5</td>
<td>38+00</td>
<td>400D/S</td>
<td>140.0</td>
<td>165.0</td>
</tr>
<tr>
<td>B-6</td>
<td>38+00</td>
<td>600D/S</td>
<td>135.0</td>
<td>165.0</td>
</tr>
<tr>
<td>B-7</td>
<td>38+00</td>
<td>985D/S</td>
<td>130.0</td>
<td>165.0</td>
</tr>
</tbody>
</table>

2J 09-21-87

INPUT DATA MENU

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ==> 4

PIEZOMETER AND POOL READING INPUT

PI AND POOL READINGS IN A FILE? (Y/N) N

2J 09-21-87

NUMBER OF DATES (<50) ==> 1

2J 09-21-87

DATE # 1

DATE OF READING (MAX=10 CHRS) ==> 05/09/1973
POOL READING ==> 178.2
NUMBER OF PIEZOMETERS ==> 5

B14
Cross Section 5, Input Data, Piezometer and Pool Reading

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<tbody>
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<td>B-3</td>
</tr>
<tr>
<td>PZ READING</td>
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<tr>
<td>2J 09-21-87</td>
<td>10:40:17</td>
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</tbody>
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<tr>
<th>PIEZOMETER #</th>
<th>2</th>
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</thead>
<tbody>
<tr>
<td>PZ NUMBER (MAX=10 CHRS)</td>
<td>B-4</td>
</tr>
<tr>
<td>PZ READING</td>
<td>174.1</td>
</tr>
<tr>
<td>2J 09-21-87</td>
<td>10:40:32</td>
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<tr>
<td>PZ NUMBER (MAX=10 CHRS)</td>
<td>B-5</td>
</tr>
<tr>
<td>PZ READING</td>
<td>172.4</td>
</tr>
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<td>2J 09-21-87</td>
<td>10:40:44</td>
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<tr>
<td>PZ NUMBER (MAX=10 CHRS)</td>
<td>B-6</td>
</tr>
<tr>
<td>PZ READING</td>
<td>167.3</td>
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<td>2J 09-21-87</td>
<td>10:40:57</td>
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<td>PZ NUMBER (MAX=10 CHRS)</td>
<td>B-7</td>
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<tr>
<td>PZ READING</td>
<td>172.5</td>
</tr>
<tr>
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<td>10:41:10</td>
</tr>
</tbody>
</table>

WANT TO SAVE DATA READINGS? (Y/N) N
2J 09-21-87 | 10:42:12

PIEZOMETER READINGS

| # OF PZ READINGS | 5 |

<table>
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<tr>
<th>PNO</th>
<th>PDTRD</th>
<th>PREAD</th>
<th>POOLRD</th>
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<tbody>
<tr>
<td>B-3</td>
<td>05/09/1973</td>
<td>175.3</td>
<td>178.2</td>
</tr>
<tr>
<td>B-4</td>
<td>05/09/1973</td>
<td>174.1</td>
<td>178.2</td>
</tr>
<tr>
<td>B-5</td>
<td>05/09/1973</td>
<td>172.4</td>
<td>178.2</td>
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<td>05/09/1973</td>
<td>167.3</td>
<td>178.2</td>
</tr>
<tr>
<td>B-7</td>
<td>05/09/1973</td>
<td>172.5</td>
<td>178.2</td>
</tr>
</tbody>
</table>
Cross Section 5, Input Data, Control Measure Unit Cost

2J 09-21-87

INPUT DATA MENU

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ==> 5
2J 09-21-87

CONTROL MEASURE UNIT COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. END INPUT

ENTER NUMBER OF CHOICE ==> 1
2J 09-21-87

BERM COST INPUT

DO YOU WANT TO INPUT COST FROM FILE? (Y/N) N
UNSPECIFIED BERM (DEFAULT=$1.30/CU YD) ==> 
IMPERVIOUS BERM (DEFAULT=$1.30/CU YD) ==> 
SEMIPERVIOUS BERM (DEFAULT=$1.30/CU YD) ==> 
SAND BERM (DEFAULT=$3.75/CU YD) ==> 
PERVIOUS BERM W/ COLLECTOR PIPE (NO DEFAULT) ==> 
ROCK ISLAND BERM (DEFAULT=$3.75/CU YD) ==> 
WANT TO SAVE UNIT COST? (Y/N) N
2J 09-21-87

BERM UNIT COSTS

UNSPECIFIED BERM ............ $ 1.30/CU YD
IMPERVIOUS BERM ............ $ 1.30/CU YD
SEMIPERVIOUS BERM ............ $ 1.30/CU YD
SAND BERM .................... $ 3.75/CU YD
PERVIOUS BERM W/ COLL. PIPE . UNDEFINED
ROCK ISLAND BERM ............ $ 3.75/CU YD

B16
Cross Section 5, Input Data, Control Measure Unit Cost

2J 09-21-87

CONTROL MEASURE UNIT COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. END INPUT

ENTER NUMBER OF CHOICE ==> 2

2J 09-21-87

BLANKET COST INPUT

DO YOU WANT TO INPUT COST FROM FILE? (Y/N) N
BLANKET UNIT COST (DEFAULT=$1.20/CU YD) ==> 1.20/CU YD
WANT TO SAVE UNIT COST? (Y/N) N

2J 09-21-87

CONTROL MEASURE UNIT COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. END INPUT

ENTER NUMBER OF CHOICE ==> 3

2J 09-21-87

CUTOFF UNIT COST INPUT

DO YOU WANT TO INPUT COSTS FROM FILE? (Y/N) N
Cross Section 5, Input Data, Control Measure Unit Cost

2J 09-21-87

CUTOFF DEFAULT UNIT COSTS

$3.00/SQR. FT. ABOVE 65 FT
$8.00/SQR. FT. BELOW 65 FT

DO YOU WANT DEFAULT COSTS? (Y/N) Y
2J 09-21-87

DO YOU WANT TO SAVE CUTOFF UNIT COSTS? (Y/N) N
2J 09-21-87

CUTOFF UNIT COSTS

# OF LAYERS = 2

LAYER #  COST(/FT)  DEPTH(FT)
1  $ 3.00  65.0
2  $ 8.00  -

2J 09-21-87

CONTROL MEASURE UNIT COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. END INPUT

ENTER NUMBER OF CHOICE ===> 4
2J 09-21-87

RELIEF WELL UNIT COST INPUT

DO YOU WANT TO INPUT UNIT COSTS FROM FILE? (Y/N) N
2J 09-21-87

FOR DEFAULT VALUES, PRESS <RETURN>
Cross Section 5, Input Data, Control Measure Unit Cost

DRT : COST OF DRILLING THROUGH TOPSTRATUM ($/FT)  
(DEFAULT=$20.00/FT) ===> 

DRP : COST OF DRILLING THROUGH FOUNDATION ($/FT)  
(DEFAULT=$16.00) ===> 

RP : COST OF RISER PIPE ($/FT FOR 8 IN. DIA. PIPE)  
STAINLESS STEEL ....... $80.00/FT  
GALVANIZED STEEL ...... $40.00/FT  
PLASTIC, PVC ........... $30.00/FT  
ENTER COST ===> 30.00  

WS : COST OF WELL SCREEN ($/FT FOR 8 IN. DIA. SCREEN)  
STAINLESS STEEL ...... $125.00/FT  
GALVANIZED STEEL ...... $75.00/FT  
PLASTIC, PVC ........... $85.00/FT  
ENTER COST ===> 85.00  

FL : COST OF FILTER ($/FT)  
(DEFAULT=$12.00) ===> 

BF : COST OF BACKFILLING ($)  
(DEFAULT=$400.00) ===> 

WC : COST OF WELL COVER ($)  
(DEFAULT=$300.00) ===> 

WD : COST OF WELL DEVELOPMENT AND TEST ($)  
(DEFAULT=$1000.00) ===> 

DO YOU WANT TO SAVE UNIT COST? (Y/N) N  
2J 09-21-87 10:45:34

RELIEF WELL UNIT COSTS
----------------------------------------
DRT = $ 20.00 /FT  
DRP = $ 16.00 /FT  
RP = $ 30.00 /FT  
WS = $ 85.00 /FT  
FL = $ 12.00  
BF = $ 400.00  
WC = $ 300.00  
WD = $ 1000.00  
2J 09-21-87 10:45:55

CONTROL MEASURE UNIT COST MENU
----------------------------------------
1. BERM  
2. RIVERSIDE BLANKET  
3. CUTOFF  
4. RELIEF WELL  
5. END INPUT  

ENTER NUMBER OF CHOICE ===> 5
Cross Section 5, Input Data

INPUT DATA MENU
-------------------

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ====> 6
2J 09-21-87

LEVEE UNDERSEEPAGE MAIN MENU
-----------------------------

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ====> 2
2J 09-21-87

GRADIENT AND SEEPAGE CALCULATIONS MENU
----------------------------------------

1. INITIAL CONDITIONS
2. FROM PIEZOMETER DATA
3. PIEZOMETER PLOT
4. END CALCULATIONS

ENTER NUMBER OF CHOICE ====> 1
2J 09-21-87

PROJECT NAME : PROGRAM DEVELOPMENT
STATION : X-SECT. 5

INITIAL CONDITIONS
-------------------

\[
\begin{align*}
X_1 &= 200. \text{ FT} \\
X_3 &= 2048. \text{ FT} \\
M &= 1.046E-01 \\
I &= 1.964 \\
Q_S &= 154. \text{ GPM/100 FT} \\
\text{HO} &= 21.4 \text{ FT} \\
\$ &= 1.405E-01
\end{align*}
\]
Cross Section 5, Gradient and Seepage Calculations, Initial Conditions

2J 09-21-87

DEVICE DRIVER MENU
---------------------
1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==> 2

COMPUTER WORKING....

2J 09-21-87

DEVICE DRIVER MENU
---------------------
1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==> 3

2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N

B21
Cross Section 5, Gradient and Seepage Calculations, From Piezometer Data

2J 09-21-87

GRADIENT AND SEEPAGE CALCULATIONS MENU

1. INITIAL CONDITIONS
2. FROM PIEZOMETER DATA
3. PIEZOMETER PLOT
4. END CALCULATIONS

ENTER NUMBER OF CHOICE ===> 2
2J 09-21-87

PZ SEEPAGE CALCULATIONS

AVAILABLE DATES

05/09/1973

DATE TO CALCULATE ===> 05/09/1973
2J 09-21-87

PROJECT NAME : PROGRAM DEVELOPMENT
STATION : X-SECT. 5

FROM PIEZOMETER DATA

X1 = 351.7 FT
X3 = 1560.0 FT
M = .5455E-02
I = .740
QS = 80.4 GPM/100 FT
H = 13.7 FT
L1 = 420.0 FT
h1 = 10.8 FT
L2 = 200.0 FT
h2 = 9.6 FT
H0 = 8.5 FT
S = 951.7 FT

2J 09-21-87

DEVICE DRIVER MENU
Cross Section 5, Gradient and Seepage Calculations, From Piezometer Data

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 2

COMPUTER WORKING....

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87 11:05:27

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N
Cross Section 5, Gradient and Seepage Calculations, Piezometer Plot

2J 09-21-87

GRADIENT AND SEEPAE CALCULATIONS MENU
---------------------------------------------

1. INITIAL CONDITIONS
2. FROM PIEZOMETER DATA
3. PIEZOMETER PLOT
4. END CALCULATIONS

ENTER NUMBER OF CHOICE ==> 3
2J 09-21-87

FZ PLOT
-----

AVAILABLE DATES
----------------

05/09/1973

DATE TO PLOT ==> 05/09/1973
2J 09-21-87

DEVICE DRIVER MENU
-------------------

1. SCREEN (640x200 MONOCROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==> 2

COMPUTER WORKING....
Cross Section 5, Gradient and Seepage Calculations, Piezometer Plot

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==== 3

2J 09-21-87

GRADIENT AND SEEPAGE CALCULATIONS MENU

1. INITIAL CONDITIONS
2. FROM PIEZOMETER DATA
3. PIEZOMETER PLOT
4. END CALCULATIONS

ENTER NUMBER OF CHOICE ==== 4

B25
Cross Section 5, Control Measure and Cost, Berm

2J 09-21-87

LEVEE UNDERSEEPAGE MAIN MENU
----------------------------------

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ==> 3
2J 09-21-87

CONTROL MEASURE AND COST MENU
----------------------------------

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ==> 1
2J 09-21-87

BERM DESIGN
-------------

XXMIN : MINIMUM STANDARD CE BERM WIDTH (FT)
        (DEFAULT=150) ==>  
XXMAX : MAXIMUM STANDARD CE BERM WIDTH (FT)
        (DEFAULT=400) ==>  
XRMIN : MINIMUM ROCK ISLAND BERM WIDTH (FT)
        (DEFAULT=20) ==>  

2J 09-21-87

BERM SELECTION MENU
---------------------

1. IMPERVIOUS BERM
2. SEMIPERVIOUS BERM
3. PERVIOUS BERM WITH COLLECTOR PIPE
4. SAND BERM
5. ROCK ISLAND BERM

ENTER NUMBER OF CHOICE ==> 1
Cross Section 5, Control Measure and Cost, Impervious Berm

2J 09-21-87

PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

OUTPUT DATA FOR BERM ANALYSIS

-----------------------------

IMPERVIOUS BERM

X1 = 200. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED

X1 = 400. FT
T = 12.1 FT
VB = 15726. CU YD/100 FT LEVEE STATION

2J 09-21-87

BERM COST CALCULATION

-----------------------------

IMPERVIOUS BERM

VB = 15726. CU YD/100 FT LEVEE STATION
UNIT COST = $ 1.30 /CU YD
TOTAL COST = $ 20443.00 /100 FT LEVEE STATION

2J 09-21-87

DEVICE DRIVER MENU

-----------------------------

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 2

COMPUTER WORKING....
Cross Section 5, Control Measure and Cost, Impervious Berm

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N
2J 09-21-87

CONTROL MEASURE AND COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 1
Cross Section 5, Control Measure and Cost, Semipervious Berm

2J 09-21-87

BERM DESIGN

-------------

XXMIN : MINIMUM STANDARD CE BERM WIDTH (FT)
(DEFAULT=150) =>>
XXMAX : MAXIMUM STANDARD CE BERM WIDTH (FT)
(DEFAULT=400) =>>
XRMIN : MINIMUM ROCK ISLAND BERM WIDTH (FT)
(DEFAULT=20) =>>

2J 09-21-87

BERM SELECTION MENU

1. IMPERVIOUS BERM
2. SEMIPERVIOUS BERM
3. PERVERSIOUS BERM WITH COLLECTOR PIPE
4. SAND BERM
5. ROCK ISLAND BERM

ENTER NUMBER OF CHOICE => 2

2J 09-21-87

PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 5

OUTPUT DATA FOR BERM ANALYSIS

-----------------------------

SEMIPERVIOUS BERM

X1 = 200. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED

XSP= 400. FT
T = 12.1 FT
VB = 15726. CU YD/100 FT LEVEE STATION

2J 09-21-87

BERM COST CALCULATION

-----------------------

SEMIPERVIOUS BERM

VB = 15726. CU YD/100 FT LEVEE STATION
UNIT COST = $ 1.30 /CU YD
TOTAL COST = $ 20443.00 /100 FT LEVEE STATION

B29
Cross Section 5, Control Measure and Cost, Pervious Berm

2J 09-21-87

DEVICE DRIVER MENU
-----------------------
1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3

2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N

2J 09-21-87

CONTROL MEASURE AND COST MENU
---------------------------------
1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 1

2J 09-21-87

BERM DESIGN
-----------

XXMIN : MINIMUM STANDARD CE BERM WIDTH (FT)  
(DEFAULT=150) ===> 

XXMAX : MAXIMUM STANDARD CE BERM WIDTH (FT)  
(DEFAULT=400) ===> 

XRMIN : MINIMUM ROCK ISLAND BERM WIDTH (FT)  
(DEFAULT=20) ===> 

2J 09-21-87

BERM SELECTION MENU
---------------------
1. IMPERVIOUS BERM
2. SEMIPERVIOUS BERM
3. PERVERIOUS BERM WITH COLLECTOR PIPE
4. SAND BERM
5. ROCK ISLAND BERM

ENTER NUMBER OF CHOICE ===> 3
Cross Section 5, Control Measure and Cost, Pervious Berm

2J 09-21-87

PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

OUTPUT DATA FOR BERM ANALYSIS

PERVIOUS BERM WITH COLLECTOR PIPE

X1 = 200. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED

XP = 400. FT
T = 12.1 FT

VB = 15726. CU YD/100 FT LEVEE STATION

2J 09-21-87

BERM COST CALCULATION

PERVIOUS BERM WITH COLLECTOR PIPE

VB = 15726. CU YD/100 FT LEVEE STATION
UNIT COST = ? NO RECENT CONSTRUCTION EXPERIENCE
TOTAL COST = ? NO RECENT CONSTRUCTION EXPERIENCE

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N
Cross Section 5, Control Measure and Cost, Sand Berm

2J 09-21-87

CONTROL MEASURE AND COST MENU
----------------------------------
1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ==> 1

BERM DESIGN
-------------
XXMIN : MINIMUM STANDARD CE BERM WIDTH (FT) (DEFAULT=150) ==> 
XXMAX : MAXIMUM STANDARD CE BERM WIDTH (FT) (DEFAULT=400) ==> 
XRMIN : MINIMUM ROCK ISLAND BERM WIDTH (FT) (DEFAULT=20) ==> 

2J 09-21-87

BERM SELECTION MENU
---------------------
1. IMPERVIOUS BERM
2. SEMIPERVIOUS BERM
3. PERVIOUS BERM WITH COLLECTOR PIPE
4. SAND BERM
5. ROCK ISLAND BERM

ENTER NUMBER OF CHOICE ==> 4

PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 5

OUTPUT DATA FOR BERM ANALYSIS
--------------------------------

SAND BERM

X1 = 200. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED

B32
Cross Section 5, Control Measure and Cost, Sand Berm

$X = 400. \text{ FT}$
$T = 12.1 \text{ FT}$
$V_B = 15726. \text{ CU YD/100 FT LEVEE STATION}$

2J 09-21-87 11:35:42

BERM COST CALCULATION
------------------------------------

SAND BERM

$V_B = 15726. \text{ CU YD/100 FT LEVEE STATION}$
UNIT COST = $3.75 /\text{CU YD}$
TOTAL COST = $58972.00 /100 \text{ FT LEVEE STATION}$

2J 09-21-87 11:35:50

DEVICE DRIVER MENU
------------------------

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87 11:35:56

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N
2J 09-21-87 11:35:57

CONTROL MEASURE AND COST MENU
--------------------------------

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 2
2J 09-21-87 11:36:09

BLANKET ANALYSIS
----------------------

IS THERE A BORROW PIT? (Y/N) Y

B33
Cross Section 5, Control Measure and Cost, Riverside Blanket

2J 09-21-87

RIVERSIDE BLANKET ANALYSIS

XR = 4734. FT
L1 = 200. FT

IF XR OR L1 DISTANCE TO RIVER, SOLUTION INFEASIBLE

DO YOU WANT TO CONTINUE? (Y/N) Y

ZBR : TOP STRATUM THICKNESS IN BORROW PIT ==> 0
2J 09-21-87

INPUT CHOICES

1. LB, KB
2. LB, ZB
3. KB, ZB

ENTER NUMBER OF CHOICE ==> 1

LB : BLANKET WIDTH (DEFAULT=BORROW PIT WIDTH) ==> 800
2J 09-21-87

DETERMINE KB AND ZB

ENTER VALUE OF KB .. ZB IS CALCULATED
WHEN FINISHED, HIT RETURN TO CHOOSE VALUE

<table>
<thead>
<tr>
<th>KB (CM/S)</th>
<th>ZB (FT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.01 E-4</td>
<td>1A</td>
</tr>
<tr>
<td>.1 E-4</td>
<td>1A</td>
</tr>
</tbody>
</table>

ENTER VALUE OF KB TO USE ==> .1 E-4
2J 09-21-87

PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 5
Cross Section 5, Control Measure and Cost, Riverside Blanket

OUTPUT DATA FOR BLANKET ANALYSIS

\[
\begin{align*}
X1 &= 4734. \text{ FT} \\
X3 &= 2048. \text{ FT} \\
M &= 0.3930E-02 \\
I &= 0.700 \\
Qs &= 58. \text{ GPM/100 FT} \\
XR &= 4734. \text{ FT} \\
LB &= 800. \text{ FT} \\
KB &= 0.1000E-04 \text{ CM/S} \\
LD &= 3.6 \text{ FT} \\
VRB &= 10596. \text{ CU YD/100 FT LEVEE STATION} \\
\end{align*}
\]

2J 09-21-87
11:42:00

BLANKET COST CALCULATION

\[
\begin{align*}
VRB &= 10596. \text{ CU YD/100 FT LEVEE STATION} \\
\text{UNIT COST} &= \$ 1.20 /\text{CU YD} \\
\text{TOTAL COST} &= \$ 12715.00 /100 \text{ FT OF LEVEE STATION} \\
\end{align*}
\]

2J 09-21-87
11:42:07

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCROME GRAPHICS) \\
2. HEWLETT-PACKARD 7475A PLOTTER \\
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 2

COMPUTER WORKING....
Cross Section 5, Control Measure and Cost, Riverside Blanket

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N

CONTROL MEASURE AND COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 3
Cross Section 5, Control Measure and Cost, Cutoff

2J 09-21-87

CUTOFF ANALYSIS

DC/D : CUTOFF DEPTH/DEPTH RATIO ==> 0.95
2J 09-21-87

PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 5

OUTPUT DATA FOR CUTOFF ANALYSIS

DC/D = .950
X1 = 200. FT
X3 = 2048. FT
M = .1058E-01
I = 1.799
Qs = 146. GPM/100 FT

2J 09-21-87

CUTOFF COST CALCULATION

DEPTH = 52. FT
COST = $ 15600.00 /100 FT OF LEVEE STATION

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==> 2

COMPUTER WORKING....
Cross Section 5, Control Measure and Cost, Cutoff

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==> 3

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N

CONTROL MEASURE AND COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ==> 4
Cross Section 5, Control Measure and Cost, Relief Well

2J 09-21-87

RELIEF WELL CALCULATIONS

NUMBER OF LAYERS IN PERVIOUS FOUNDATION ==> 1
2J 09-21-87

PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

OUTPUT DATA FOR RELIEF WELL ANALYSIS

\[ X_1 = 200. \text{ FT} \]
\[ X_3 = 2048. \text{ FT} \]
\[ Q_S = 154. \text{ GAL/100 FT LEVEE STATION} \]

<table>
<thead>
<tr>
<th>P</th>
<th>ASEL</th>
<th>WBAR</th>
<th>QW</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>.250</td>
<td>95.</td>
<td>10.</td>
<td>372.</td>
<td>$3707.00</td>
</tr>
<tr>
<td>.375</td>
<td>127.</td>
<td>15.</td>
<td>475.</td>
<td>$3229.00</td>
</tr>
<tr>
<td>.500</td>
<td>152.</td>
<td>20.</td>
<td>575.</td>
<td>$3072.00</td>
</tr>
<tr>
<td>.625</td>
<td>171.</td>
<td>25.</td>
<td>682.</td>
<td>$3051.00</td>
</tr>
<tr>
<td>.750</td>
<td>187.</td>
<td>30.</td>
<td>731.</td>
<td>$3101.00</td>
</tr>
<tr>
<td>.875</td>
<td>199.</td>
<td>35.</td>
<td>800.</td>
<td>$3193.00</td>
</tr>
<tr>
<td>1.000</td>
<td>209.</td>
<td>40.</td>
<td>819.</td>
<td>$3311.00</td>
</tr>
</tbody>
</table>
| .625| 171. | 25.  | 682. | $3051.00 | MINIMUM COST

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==> 2

COMPUTER WORKING....
Cross Section 5, Control Measure and Cost, Relief Well

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==> 3
2J 09-21-87 12:56:14

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N
2J 09-21-87 12:58:30

CONTROL MEASURE AND COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ==> 5

B40
Cross Section 5, Control Measure and Cost, Cost Summary

PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

COST SUMMARY FOR ALL CONTROL MEASURES

<table>
<thead>
<tr>
<th>TYPE</th>
<th>VOLUME</th>
<th>UNIT COST</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNSPECIFIED BERM</td>
<td>NOT CALC.</td>
<td>$1.50</td>
<td>$2,044.00</td>
</tr>
<tr>
<td>IMPERVIOUS BERM</td>
<td>15726.</td>
<td>$1.50</td>
<td>$2,044.00</td>
</tr>
<tr>
<td>SEMIPERVIOUS BERM</td>
<td>15726.</td>
<td>$1.50</td>
<td>$2,044.00</td>
</tr>
<tr>
<td>PERVIOUS BERM</td>
<td>15726.</td>
<td>$3.75</td>
<td>$5,577.00</td>
</tr>
<tr>
<td>SAND BERM</td>
<td>15726.</td>
<td>$3.75</td>
<td>$5,577.00</td>
</tr>
<tr>
<td>ROCK ISLAND BERM</td>
<td>NOT CALC.</td>
<td>$3.75</td>
<td>$3,750.00</td>
</tr>
<tr>
<td>RIVERSIDE BLANKET</td>
<td>10596.</td>
<td>$1.20</td>
<td>$1,271.00</td>
</tr>
</tbody>
</table>

CUTOFF

RELIEF WELL - LOWEST COST

<table>
<thead>
<tr>
<th>DC/D =</th>
<th>.950</th>
<th>DEPTH =</th>
<th>25. FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEPTH =</td>
<td>52. FT</td>
<td>SPACING =</td>
<td>171. FT</td>
</tr>
<tr>
<td>TOTAL = $</td>
<td>15600.00</td>
<td>TOTAL =</td>
<td>$3051.00</td>
</tr>
</tbody>
</table>

CONTROL MEASURE AND COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 6

LEVEE UNDERSEEPAGE MAIN MENU

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ===> 4
Computer Output Cross Section 6
Using Existing Data Files

Relief Well Analysis
Cross Section 6, Input Data

LEVEE UNDERSEEPAGE MAIN MENU
----------------------------------------

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ===> 0
13:08:09
2J 09-21-87

SET UP SYSTEM
---------------

PLOTTER COMMUNICATIONS PORT

1. COM1
2. COM2

ENTER NUMBER OF CHOICE ===> COM1
ENTER NUMBER OF CHOICE ===> 1

ENTER PLOTTER BAUD RATE ===> 600
13:08:46
2J 09-21-87

LEVEE UNDERSEEPAGE MAIN MENU
----------------------------------------

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ===> 1
13:09:30
2J 09-21-87

INPUT DATA MENU
-----------------

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ===> 1
Cross Section 6, Input Data, Cross Section

2J 09-21-87

CROSS-SECTION INPUT

---

IS CROSS-SECTION IN A DATA FILE? (Y/N) Y

CROSS-SECTION FILE NAME (MAX=25 CHR$) => CROSS6

2J 09-21-87

---

# OF LINES = 7

# OF POINTS IN LINE 1 = 7

X       Y
---     ---
-510.0,  106.0
 0.0,    106.0
100.0,   139.0
120.0,   139.0
220.0,   106.0
1200.0,  106.0
1200.0,  100.0

# OF POINTS IN LINE 2 = 2

X       Y
---     ---
-510.0,  100.0
1200.0,  100.0

# OF POINTS IN LINE 3 = 2

X       Y
---     ---
-510.0,  90.0
1200.0,  90.0

# OF POINTS IN LINE 4 = 2

X       Y
---     ---
-510.0,  75.0
1200.0,  75.0

B44
Cross Section 6, Input Data, Cross Section

# OF POINTS IN LINE 5 = 2

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>-510.0</td>
<td>.0</td>
</tr>
<tr>
<td>1200.0</td>
<td>.0</td>
</tr>
</tbody>
</table>

# OF POINTS IN LINE 6 = 2

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>.0</td>
<td>106.0</td>
</tr>
<tr>
<td>.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

# OF POINTS IN LINE 7 = 2

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>220.0</td>
<td>106.0</td>
</tr>
<tr>
<td>220.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

2J 09-21-87

DO YOU WANT TO SEE GRAPH? (Y/N) N

2J 09-21-87

INPUT DATA MENU

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ==> 2

2J 09-21-87

GEOTECH PROPERTIES INPUT

DOES FILE WITH GEOTECH PROPERTIES EXIST? (Y/N) Y

GEOTECH PROPERTIES FILE NAME (MAX=25 CHRS) ==> GEO6.DAT

B45
Cross Section 6, Input Data, Geotech Properties

2J 09-21-87

PROJECT NAME: PROGRAM DEVELOPMENT
STATION: X-SECT. 6

GENERAL CONTROL MEASURE INPUT DATA
--------------------------------------------------
L hE = 106 FT
H = 30 FT
LTO = 100 FT RTQ = 120 FT
L1 = 980 FT ENTRANCE = OPEN
L3 = INFINITE FT EXIT = INFINITE

D = 100 FT DD = 210 FT
ZBL = 6 FT KBL = 0.0003 CM/S
ZBR = 6 FT KBR = 0.0003 CM/S
ZT = 6 FT KF = 0.045 CM/S
ZL = 6 FT

SUBWT = 50. LB/CU FT

2J 09-21-87

SUPPLEMENTAL CONTROL MEASURE INPUT DATA
--------------------------------------------------

<table>
<thead>
<tr>
<th>BERM</th>
<th>RIVERSIDE BLANKET</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSB = UNDEFINED</td>
<td>IA = UNDEFINED</td>
</tr>
<tr>
<td>I0B = UNDEFINED</td>
<td>M3R = UNDEFINED</td>
</tr>
<tr>
<td>I1 = UNDEFINED</td>
<td>M4 = UNDEFINED</td>
</tr>
<tr>
<td>M1 = UNDEFINED</td>
<td></td>
</tr>
<tr>
<td>M3B = UNDEFINED</td>
<td></td>
</tr>
</tbody>
</table>

CUTOFF
-------
NO SPECIAL INPUT REQUIRED

<table>
<thead>
<tr>
<th>RELIEF WELL</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSW = UNDEFINED</td>
</tr>
<tr>
<td>IOW = 0.534</td>
</tr>
<tr>
<td>RW = 1.0 FT</td>
</tr>
<tr>
<td>DP = 0.67 FT</td>
</tr>
<tr>
<td>RUFF = 0.0001</td>
</tr>
<tr>
<td>VISCOS = 0.0000121 GAL*FT/SEC</td>
</tr>
<tr>
<td>J = UNDEFINED %</td>
</tr>
<tr>
<td>HEL = 0.33 FT</td>
</tr>
</tbody>
</table>

2J 09-21-87

INPUT DATA MENU
Cross Section 6, Input Data, Control Measure Unit Costs

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ==> 5

CONTROL MEASURE UNIT COST MENU
---------------------------------------

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. END INPUT

ENTER NUMBER OF CHOICE ==> 4

RELIEF WELL UNIT COST INPUT
-----------------------------

DO YOU WANT TO INPUT UNIT COSTS FROM FILE? (Y/N) Y
FILE NAME (MAX=25 CHRS) ==> WELL.CST

RELIEF WELL UNIT COSTS
-----------------------

DRT = $ 20.00 /FT
DRP = $ 16.00 /FT
RP = $ 30.00 /FT
WS = $ 85.00 /FT
FL = $ 12.00
BF = $ 400.00
WC = $ 300.00
WD = $ 1000.00

2J 09-21-87

CONTROL MEASURE UNIT COST MENU
---------------------------------------

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
Cross Section 6, Gradient and Seepage Calculations, Initial Conditions

4. RELIEF WELL
5. END INPUT

ENTER NUMBER OF CHOICE ==> 5
2J 09-21-87 13:13:38

INPUT DATA MENU

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ==> 6
2J 09-21-87 13:14:07

LEVEE UNDERSEEPAE MAIN MENU

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ==> 2
2J 09-21-87 13:15:01

GRADIENT AND SEEPAE CALCULATIONS MENU

1. INITIAL CONDITIONS
2. FROM PIEZOMETER DATA
3. PIEZOMETER PLOT
4. END CALCULATIONS

ENTER NUMBER OF CHOICE ==> 1
2J 09-21-87 13:15:18

PROJECT NAME : PROGRAM DEVELOPMENT
STATION : X-SECT. 6

INITIAL CONDITIONS

\[ \begin{align*}
X_1 &= 425. \text{ ft} \\
X_3 &= 435. \text{ ft}
\end{align*} \]
Cross Section 6, Gradient and Seepage Calculations, Initial Conditions

\[ M = 0.2778E-01 \]
\[ I = 2.013 \]
\[ QS = 387 \text{ GPM/100 FT} \]
\[ HO = 12.1 \text{ FT} \]
\[ \$ = 0.1944 \]

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N
2J 09-21-87

GRADIENT AND SEEPAGE CALCULATIONS MENU

1. INITIAL CONDITIONS
2. FROM PIEZOMETER DATA
3. PIEZOMETER PLOT
4. END CALCULATIONS

ENTER NUMBER OF CHOICE ===> 4
2J 09-21-87

LEVEE UNDERSEEPAGE MAIN MENU

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ===> 3
Cross Section 6, Control Measure and Cost, Relief Well

2J 09-21-87

CONTROL MEASURE AND COST MENU
----------------------------------------

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ==> 4
2J 09-21-87

RELIEF WELL CALCULATIONS
---------------------------

NUMBER OF LAYERS IN PERVIOUS FOUNDATION ==> 3

LAYER # 1
-----------------
DN : THICKNESS OF LAYER (FT) ==> 10
KHN : HORIZONTAL PERMEABILITY (CM/S) ==> 0.0125

LAYER # 2
-----------------
DN : THICKNESS OF LAYER (FT) ==> 15
KHN : HORIZONTAL PERMEABILITY (CM/S) ==> 0.02

LAYER # 3
-----------------
DN : THICKNESS OF LAYER (FT) ==> 75
KHN : HORIZONTAL PERMEABILITY (CM/S) ==> 0.12
2J 09-21-87

PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 6

OUTPUT DATA FOR RELIEF WELL ANALYSIS
-----------------------------------------

x1 = 425. FT
x3 = 435. FT
Q5 = 386. GAL/100 FT LEVEE STATION
Cross Section 6, Control Measure and Cost, Relief Well

<table>
<thead>
<tr>
<th>P</th>
<th>ASEL</th>
<th>WBAR</th>
<th>QW</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>.250</td>
<td>50.</td>
<td>41.</td>
<td>217.</td>
<td>$13309.00</td>
</tr>
<tr>
<td>.375</td>
<td>65.</td>
<td>51.</td>
<td>271.</td>
<td>$11938.00</td>
</tr>
<tr>
<td>.500</td>
<td>77.</td>
<td>61.</td>
<td>319.</td>
<td>$11583.00</td>
</tr>
<tr>
<td>.625</td>
<td>86.</td>
<td>71.</td>
<td>389.</td>
<td>$11556.00</td>
</tr>
<tr>
<td>.750</td>
<td>95.</td>
<td>80.</td>
<td>450.</td>
<td>$11719.00</td>
</tr>
<tr>
<td>.875</td>
<td>102.</td>
<td>90.</td>
<td>468.</td>
<td>$11983.00</td>
</tr>
<tr>
<td>1.000</td>
<td>108.</td>
<td>100.</td>
<td>515.</td>
<td>$12313.00</td>
</tr>
</tbody>
</table>

.625  86.  71.  389.  $11556.00  MINIMUM COST

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==> 2

COMPUTER WORKING....

B51
Cross Section 6, Control Measure and Cost, Cost Summary

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3

2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N

CONTROL MEASURE AND COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUT-OFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 5

2J 09-21-87

PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 6

COST SUMMARY FOR ALL CONTROL MEASURES

<table>
<thead>
<tr>
<th>TYPE</th>
<th>VOLUME</th>
<th>UNIT COST</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNSPECIFIED BERM</td>
<td>NOT CALCULATED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMPERVIOUS BERM</td>
<td>NOT CALCULATED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEMIPERVIOUS BERM</td>
<td>NOT CALCULATED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PERVERVIOUS BERM</td>
<td>NOT CALCULATED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAND BERM</td>
<td>NOT CALCULATED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROCK ISLAND BERM</td>
<td>NOT CALCULATED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIVERSIDE BLANKET</td>
<td>NOT CALCULATED</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CUTOFF

DC/D = UNDEFINED
DEPTH = 71. FT

RELIEF WELL - LOWEST COST

DEPTH = 71. FT
SPACING = 36. FT
TOTAL = $ 11556.00

B52
CONTROL MEASURE AND COST MENU
---------------------------------

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 6

LEVEE UNDERSEEPAGE MAIN MENU
---------------------------------

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ===> 4

C:\marty\levee>LEVSEEP
Computer Output Cross Section 7
Using Existing Data Files

Rock Island Example
Cross Section 7, Input Data, Cross Section

2J 09-21-87

LEV EE UNDERSEE EPAGE MAIN MENU
-----------------------------

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ==> 0
2J 09-21-87

SET UP SYSTEM
-------------

PLOTTER COMMUNICATIONS PORT

1. COM1
2. COM2

ENTER NUMBER OF CHOICE ==> 1

ENTER PLOTTER BAUD RATE ==> 600
2J 09-21-87

LEV EE UNDERSEE EPAGE MAIN MENU
-----------------------------

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ==> 1
2J 09-21-87

INPUT DATA MENU
----------------

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ==> 1

B55
Cross Section 7, Input Data, Cross Section

2J 09-21-87

CROSS-SECTION INPUT

IS CROSS-SECTION IN A DATA FILE? (Y/N) Y
CROSS-SECTION FILE NAME (MAX=25 CHR) ===> CROSS7
2J 09-21-87

CROSS-SECTION

# OF LINES = 5

# OF POINTS IN LINE 1 = 6

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>380.0</td>
<td>456.3</td>
</tr>
<tr>
<td>180.0</td>
<td>456.3</td>
</tr>
<tr>
<td>98.0</td>
<td>476.0</td>
</tr>
<tr>
<td>85.0</td>
<td>476.0</td>
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<tr>
<td>0.0</td>
<td>453.7</td>
</tr>
<tr>
<td>-490.0</td>
<td>453.7</td>
</tr>
</tbody>
</table>

# OF POINTS IN LINE 2 = 5

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>380.0</td>
<td>456.3</td>
</tr>
<tr>
<td>380.0</td>
<td>449.4</td>
</tr>
<tr>
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<td>449.4</td>
</tr>
<tr>
<td>33.0</td>
<td>446.3</td>
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<tr>
<td>-490.0</td>
<td>446.3</td>
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# OF POINTS IN LINE 3 = 2

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</tr>
<tr>
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<td>338.3</td>
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</table>

# OF POINTS IN LINE 4 = 2

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<tbody>
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</tbody>
</table>

b56
Cross Section 7, Input Data, Cross Section

180.0,  456.3
180.0,  449.4

# OF POINTS IN LINE   5 =  2

<table>
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<tr>
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</thead>
<tbody>
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<td>453.7</td>
</tr>
<tr>
<td>0.0</td>
<td>446.3</td>
</tr>
</tbody>
</table>

2J 09-21-87

DO YOU WANT TO SEE GRAPH? (Y/N)  N
2J 09-21-87

INPUT DATA MENU

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ====> 2
2J 09-21-87

GEOTECH PROPERTIES INPUT

DOES FILE WITH GEOTECH PROPERTIES EXIST? (Y/N)  Y

GEOTECH PROPERTIES FILE NAME (MAX=25 CHRS) ===> GE07.DAT
2J 09-21-87

PROJECT NAME : PROGRAM DEVELOPMENT
STATION : X-SECT. 7

GENERAL CONTROL MEASURE INPUT DATA

LTE = 453.7      FT
H   = 22.3       FT
LTO = 0          FT  RTO = 180       FT
L1  = 200        FT  ENTRANCE = OPEN
L3  = INFINITE   FT  EXIT    = INFINITE
Cross Section 7, Input Data, Geotech Properties

D = 108 FT       DD = 108 FT
ZBL = 7.4 FT     KBL = .0015 CM/S
ZBR = 6.9 FT     KBR = .00075 CM/S
ZT = 7.4 FT      KF = .15 CM/S
ZL = 7.4 FT

SUBWT = 53 LB/CU FT

2J 09-21-87  13:30:05

SUPPLEMENTAL CONTROL MEASURE INPUT DATA

BERM
-----
FSB = UNDEFINED
IOB = .34
I1 = 0.8
M1 = .26
M3B = .20

RIVERSIDE BLANKET

IA = 0.7
M3R = .20
M4 = .25

CUTOFF
-----
NO SPECIAL INPUT REQUIRED

RELIEF WELL

FSW = 1.5
IOW = .566
RW = 1.0 FT
DP = 0.67 FT
RUFF = .0001
VISCOS = 0.0000121 GAL*FT/SEC
J = UNDEFINED %
HEL = 0.33 FT

2J 09-21-87  13:30:20

INPUT DATA MENU

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ==> 5

2J 09-21-87  13:30:35

CONTROL MEASURE UNIT COST MENU

B58
Cross Section 7, Input Data, Control Measure and Unit Cost

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. END INPUT

ENTER NUMBER OF CHOICE ==> 1
2J 09-21-87

BERM COST INPUT

DO YOU WANT TO INPUT COST FROM FILE? (Y/N) Y
FILE NAME (MAX=25 CHRS) ==> BERM.CST
2J 09-21-87

BERM UNIT COSTS

UNSPECIFIED BERM .............. $ 1.30/CU YD
IMPERVIOUS BERM .............. $ 1.30/CU YD
SEMIPERVIOUS BERM .............. $ 1.30/CU YD
SAND BERM ................. $ 3.75/CU YD
PERVIOUS BERM W/ COLL. PIPE UNDEFINED
ROCK ISLAND BERM .............. $ 3.75/CU YD
2J 09-21-87

CONTROL MEASURE UNIT COST MENU

DO YOU WANT TO INPUT COST FROM FILE? (Y/N) Y
FILE NAME (MAX=25 CHRS) ==> BLNK.CST
2J 09-21-87

BLANKET COST INPUT

BLANKET UNIT COST

BLANKET .............. $ 1.20/CU YD
B59
Cross Section 7, Input Data, Control Measure and Unit Cost

2J 09-21-87

CONTROL MEASURE UNIT COST MENU
-----------------------------------
1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. END INPUT

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87

CUTOFF UNIT COST INPUT
-----------------------
DO YOU WANT TO INPUT COSTS FROM FILE? (Y/N) Y
FILE NAME (MAX=25 CHRS) ===> CUTF.CST
2J 09-21-87

CUTOFF UNIT COSTS
-------------------
# OF LAYERS = 2
LAYER #  COST (/FT)  DEPTH (FT)
1   $3.00  65.0
2   $8.00  -

2J 09-21-87

CONTROL MEASURE UNIT COST MENU
-----------------------------------
1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. END INPUT

ENTER NUMBER OF CHOICE ===> 4
2J 09-21-87

RELIEF WELL UNIT COST INPUT
-----------------------------
DO YOU WANT TO INPUT UNIT COSTS FROM FILE? (Y/N) Y
FILE NAME (MAX=25 CHRS) ===> WELL.CST

B60
Cross Section 7, Input Data, Control Measure and Unit Cost

2J 09-21-87

RELIEF WELL UNIT COSTS

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DRT</td>
<td>=</td>
<td>$20.00</td>
<td>/FT</td>
</tr>
<tr>
<td>DPR</td>
<td>=</td>
<td>$16.00</td>
<td>/FT</td>
</tr>
<tr>
<td>RP</td>
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<td>=</td>
<td>$85.00</td>
<td>/FT</td>
</tr>
<tr>
<td>FL</td>
<td>=</td>
<td>$12.00</td>
<td></td>
</tr>
<tr>
<td>BF</td>
<td>=</td>
<td>$400.00</td>
<td></td>
</tr>
<tr>
<td>WC</td>
<td>=</td>
<td>$300.00</td>
<td></td>
</tr>
<tr>
<td>WD</td>
<td>=</td>
<td>$1000.00</td>
<td></td>
</tr>
</tbody>
</table>

2J 09-21-87

CONTROL MEASURE UNIT COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. END INPUT

ENTER NUMBER OF CHOICE ===> 5

2J 09-21-87

INPUT DATA MENU

1. CROSS SECTION
2. GEOTECH PROPERTIES
3. PIEZOMETER LOCATIONS
4. PIEZOMETER AND POOL READINGS
5. CONTROL MEASURE UNIT COSTS
6. END INPUT

ENTER NUMBER OF CHOICE ===> 6

2J 09-21-87

LEVEE UNDERSEEPAGE MAIN MENU

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ===> 2

B61
Cross Section 7, Gradient and Seepage Calculations, Initial Conditions

2J 09-21-87

GRIDIENT AND SEEPAGE CALCULATIONS MENU

1. INITIAL CONDITIONS
2. FROM PIEZOMETER DATA
3. PIEZOMETER PLOT
4. END CALCULATIONS

ENTER NUMBER OF CHOICE ===> 1
2J 09-21-87

PROJECT NAME : PROGRAM DEVELOPMENT
STATION : X-SECT. 7

INITIAL CONDITIONS

X1 = 184. FT
X3 = 283. FT
M = .3449E-01
I = 1.318
QS = 823. GPM/100 FT
H0 = 9.8 FT
$ = .1670

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N

2J 09-21-87

GRADIENT AND SEEPAGE CALCULATIONS MENU

1. INITIAL CONDITIONS
2. FROM PIEZOMETER DATA
3. PIEZOMETER PLOT
4. END CALCULATIONS

ENTER NUMBER OF CHOICE ===> 4
Cross Section 7, Control Measure and Cost, Berm

2J 09-21-87

LEVEE UNDERSEEPAGE MAIN MENU
---------------------------------------------

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87

CONTROL MEASURE AND COST MENU
---------------------------------------------

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 1
2J 09-21-87

BERM DESIGN
-------------

XXMIN : MINIMUM STANDARD CE BERM WIDTH (FT)
(DEFAULT=150) ===> 
XXMAX : MAXIMUM STANDARD CE BERM WIDTH (FT)
(DEFAULT=400) ===> 
XRMIN : MINIMUM ROCK ISLAND BERM WIDTH (FT)
(DEFAULT=20) ===> 

2J 09-21-87

BERM SELECTION MENU

1. IMPERVIOUS BERM
2. SEMIPERVIOUS BERM
3. PERVIOUS BERM WITH COLLECTOR PIPE
4. SAND BERM
5. ROCK ISLAND BERM

ENTER NUMBER OF CHOICE ===> 4
Cross Section 7, Control Measure and Cost, Sand Berm

2J 09-21-87

PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 7

OUTPUT DATA FOR BERM ANALYSIS

SAND BERM

$X_1 = 184$ FT
$X_3 = UNDEFINED$
$M = UNDEFINED$
$I = UNDEFINED$
$Q_0 = UNDEFINED$

$X_S = 177$ FT
$T = 7.5$ FT
$V_B = 3448.0$ CU YD/100 FT LEVEE STATION

2J 09-21-87

BERM COST CALCULATION

SAND BERM

$V_B = 3448.0$ CU YD/100 FT LEVEE STATION
UNIT COST = $3.75 /CU YD
TOTAL COST = $12929.00 /100 FT LEVEE STATION

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===>$ 3
2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N
2J 09-21-87

CONTROL MEASURE AND COST MENU
Cross Section 7, Control Measure and Cost, Rock Island Berm

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 1
2J 09-21-87

BERM DESIGN

XXMIN : MINIMUM STANDARD CE BERM WIDTH (FT) (DEFAULT=150) ===>
XXMAX : MAXIMUM STANDARD CE BERM WIDTH (FT) (DEFAULT=400) ===>
XRMIN : MINIMUM ROCK ISLAND BERM WIDTH (FT) (DEFAULT=20) ===>
2J 09-21-87

BERM SELECTION MENU

1. IMPERVIOUS BERM
2. SEMIPERVIOUS BERM
3. PERVIOUS BERM WITH COLLECTOR PIPE
4. SAND BERM
5. ROCK ISLAND BERM

ENTER NUMBER OF CHOICE ===> 5

CW : CREEP RATIO (DEFAULT=10) ===>
2J 09-21-87

PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 7

OUTPUT DATA FOR BERM ANALYSIS

----------------------------------------

ROCK ISLAND BERM

X1 = 184. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
Gs = UNDEFINED
Cross Section 7, Control Measure and Cost, Rock Island Berm

XRI = 43. FT
T = 3.1 FT
VB = 522. CU YD/100 FT LEVEE STATION

2J 09-21-87

BERM COST CALCULATION

ROCK ISLAND BERM

VB = 522. CU YD/100 FT LEVEE STATION
UNIT COST = $ 3.75 /CU YD
TOTAL COST = $ 1958.00 /100 FT LEVEE STATION

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ==> 2

COMPUTER WORKING...
Cross Section 7, Control Measure and Cost, Riverside Blanket

2J 09-21-87

DEVICE DRIVER MENU
---------------------
1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N
2J 09-21-87

CONTROL MEASURE AND COST MENU
---------------------------------
1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 2
2J 09-21-87

BLANKET ANALYSIS
-----------------

IS THERE A BORROW PIT? (Y/N) N
2J 09-21-87

RIVERSIDE BLANKET ANALYSIS
---------------------------

XR = 754. FT
L1 = 200. FT

IF XR OR L1 > DISTANCE TO RIVER, SOLUTION INFEASIBLE

DO YOU WANT TO CONTINUE? (Y/N) N
2J 09-21-87

CONTROL MEASURE AND COST MENU
---------------------------------
Cross Section 7, Control Measure and Cost, Cutoff

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87

CUTOFF ANALYSIS

DC/D : CUTOFF DEPTH/DEPTH RATIO ===> 0.95
2J 09-21-87

PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 7

OUTPUT DATA FOR CUTOFF ANALYSIS

<table>
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<th>DC/D</th>
<th>.950</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>184. FT</td>
</tr>
<tr>
<td>X3</td>
<td>283. FT</td>
</tr>
<tr>
<td>M</td>
<td>.2907E-01</td>
</tr>
<tr>
<td>I</td>
<td>1.023</td>
</tr>
<tr>
<td>Qs</td>
<td>489. GPM/100 FT</td>
</tr>
</tbody>
</table>

2J 09-21-87

CUTOFF COST CALCULATION

DEPTH = 110. FT
COST = $ 55500.00 /100 FT OF LEVEE STATION

2J 09-21-87

DEVICE DRIVER MENU

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. HEWLETT-PACKARD 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3

B68
Cross Section 7, Control Measure and Cost, Relief Well

2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N
2J 09-21-87

CONTROL MEASURE AND COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ==> 4
2J 09-21-87

RELIEF WELL CALCULATIONS

NUMBER OF LAYERS IN PERVERIOUS FOUNDATION ==> 1
2J 09-21-87

PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 7

OUTPUT DATA FOR RELIEF WELL ANALYSIS

X1 = 184. FT
X3 = 283. FT
Q5 = 822. GAL/100 FT LEVEE STATION

<table>
<thead>
<tr>
<th>P</th>
<th>ASEL</th>
<th>WBAR</th>
<th>QW</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>.250</td>
<td>58.</td>
<td>27.</td>
<td>359.</td>
<td>$ 8877.00</td>
</tr>
<tr>
<td>.375</td>
<td>71.</td>
<td>41.</td>
<td>557.</td>
<td>$ 9310.00</td>
</tr>
<tr>
<td>.500</td>
<td>82.</td>
<td>54.</td>
<td>616.</td>
<td>$ 9913.00</td>
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<tr>
<td>.625</td>
<td>91.</td>
<td>68.</td>
<td>744.</td>
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</tr>
<tr>
<td>.750</td>
<td>97.</td>
<td>81.</td>
<td>847.</td>
<td>$11546.00</td>
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<tr>
<td>.875</td>
<td>102.</td>
<td>95.</td>
<td>790.</td>
<td>$12484.00</td>
</tr>
<tr>
<td>1.000</td>
<td>106.</td>
<td>108.</td>
<td>847.</td>
<td>$13482.00</td>
</tr>
</tbody>
</table>
| .250| 58.  | 27.  | 359. | $ 8877.00 (== MINIMUM COST

2J 09-21-87

DEVICE DRIVER MENU
Cross Section 7, Control Measure and Cost, Cost Summary

1. SCREEN (640x200 MONOCHROME GRAPHICS)
2. Hewlett-Packard 7475A PLOTTER
3. END OF PLOTTING

ENTER NUMBER OF CHOICE ===> 3
2J 09-21-87

DO YOU WANT TO SAVE CALCULATED DATA? (Y/N) N
2J 09-21-87

CONTROL MEASURE AND COST MENU

1. BERM
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 5
2J 09-21-87

PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 7

COST SUMMARY FOR ALL CONTROL MEASURES

<table>
<thead>
<tr>
<th>TYPE</th>
<th>VOLUME</th>
<th>UNIT COST</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNSPECIFIED BERM</td>
<td>NOT CALCULATED</td>
<td>$1.30</td>
<td></td>
</tr>
<tr>
<td>IMPERVIOUS BERM</td>
<td>NOT CALCULATED</td>
<td>$1.30</td>
<td></td>
</tr>
<tr>
<td>SEMIPERVIOUS BERM</td>
<td>NOT CALCULATED</td>
<td>$1.30</td>
<td></td>
</tr>
<tr>
<td>PERVIOUS BERM</td>
<td>NOT CALCULATED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAND BERM</td>
<td>3448 ft²</td>
<td>$3.75</td>
<td>$12,729.00</td>
</tr>
<tr>
<td>ROCK ISLAND BERM</td>
<td>522 ft²</td>
<td>$3.75</td>
<td>$1,958.00</td>
</tr>
<tr>
<td>RIVERSIDE BLANKET</td>
<td>NOT CALCULATED</td>
<td>$1.20</td>
<td></td>
</tr>
</tbody>
</table>

CUTOFF

RELIEF WELL - LOWEST COST

<table>
<thead>
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<th>DEPTH</th>
<th>SPACING</th>
<th>TOTAL</th>
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</thead>
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<tr>
<td>0.950</td>
<td>27 ft</td>
<td>50 ft</td>
<td>8877.00</td>
</tr>
</tbody>
</table>

TOTAL = $55500.00
Cross Section 7, Control Measure and Cost, End

2J 09-21-87

CONTROL MEASURE AND COST MENU

-------------------------------------------------

1. BERN
2. RIVERSIDE BLANKET
3. CUTOFF
4. RELIEF WELL
5. COST SUMMARY
6. END

ENTER NUMBER OF CHOICE ===> 6

2J 09-21-87

LEVY UNDERSEEPAGE MAIN MENU

-------------------------------------------------

0. SET UP SYSTEM FOR PLOTTER
1. INPUT DATA
2. GRADIENT AND SEEPAGE CALCULATIONS
3. CONTROL MEASURE AND COST
4. END PROGRAM

ENTER NUMBER OF CHOICE ===> 4

C:\marty\levee>
APPENDIX C: VALIDATION

CONTENT

PART I: TECHNICAL DISCUSSION OF ANALYTIC PROCEDURES IN LEVSEEP

General.................................................................................. C2
Input and Seepage Calculations for LEVSEEP.......................... C3
Control Measures...................................................................... C3
Cost Summary.......................................................................... C7

PART II: COMPARISON OF COMPUTER RESULTS WITH HAND CALCULATIONS

Description of Cross Sections.................................................. C8
Evaluation of Computer Results............................................. C9
Cost comparisons..................................................................... C11
PART I: TECHNICAL DISCUSSION OF ANALYTIC PROCEDURES IN LEVSEEP

General

1. Analytical work for this study included the development of the Levee Underseepage and Control Measure Analysis Program (LEVSEEP) for operation on the IBM PC. The minimum hardware configuration is an IBM or compatible PC with 512K bytes of memory and an 8087 math coprocessor. Output may be directed to Epson and compatible printers as well as Hewlett Packard and compatible plotters. This program includes working parts of three programs identified as PZPRO II, CONTROL, and COST developed as part of the previous effort. However, these old programs have been significantly modified and have lost their identity in the new program LEVSEEP. The new program now has a common file for all general input data, and the user friendliness has been greatly improved.

2. The procedures for berm analysis reflect the current Corps guidance (EM 1110-2-1913, 1978). The procedures for riverside blanket analysis are as presented in Technical Memorandum 3-424 (WES 1956).* Procedures for analysis of cutoffs are based on the method of fragments as presented by Harr (1962). The procedures for relief well system analysis reflect current Corps guidance (EM 1110-2-1913, 1978). Specific equations and procedures used for well analysis were taken from Technical Memorandum 3-424 (WES 1956) and Engineer Bulletin 55-11 (1955). The well procedure is for infinite, partially penetrating or fully penetrating well systems under artesian flow; it does not apply to finite length systems or pumped systems. Special features for the various analyses are described in the following section. Flow diagrams (Figures C1 through C4) of the program are included to clarify procedures and to facilitate future modifications. The notations which follow those in EM 1110-2-1913 are consistently employed throughout these programs and are conveniently defined in alphabetical order in Appendix A. Supplemental computer notations are also included in Appendix A.

* References cited in this appendix are included in the References at the end of the main text.
Input and Seepage Calculations for LEVSEEP

3. The program main menu is shown in the flow diagram (Figure C1). The input is menu driven, as described in Part III of this report. Input subroutine flow diagrams are shown in Figure C2. Unit construction costs are input for later construction cost calculation for all control measures. Default values for each element of cost are provided and are based on current experience in the Mississippi River Valley. Default unit costs in the program are shown in Appendix D. The user may enter other cost figures for any element if it is desired. No provision is made for overhead, contingencies, or maintenance in the cost estimates.

4. This program calculates seepage flow and substratum pressure for either (a) physical and geometric properties or (b) field piezometer readings. It also calculates the effect of various control measures on seepage flow and substratum pressure for those cases for which published Corps procedures exist.

5. The seepage calculation subroutines are shown in Figure C3. When calculating initial conditions from physical and geometric properties, nine distinct cases based on top stratum conditions are considered; the first seven are described in EM 1110-2-1913 (1978) and the last two are combinations of semipervious and impervious landside and riverside top stratum added for completeness.

Control Measures

Berms and riverside blankets

6. Flow diagrams for the control measure subroutines are shown in Figure C4. Landside berms are analyzed in accordance with EM 1110-2-1913 (1978). Nine major cases are considered as indicated on sheet 2 of Figure C4. Riverside blankets are analyzed using the equations of WES (1956). Four major cases are analyzed as indicated on sheet 3 of Figure C4.

Cutoffs

7. With the concurrence of the Contracting Officer's Representative, the design of cutoffs to control seepage is calculated using the methods of fragments (Harr 1962). As many as five fragments are used, as shown in Figure C5. The form factors for these fragments are as follows:
\[
\phi_1 = \frac{x_1}{d} = 0.43
\]

\[
\phi_2 = \frac{x_1}{d} = 2
\]

\[
\phi_3 = \ln\left(1 + \frac{d}{d - d_c}\right) + \frac{L_2 - d_c}{d} = \ln\left(\frac{1}{1 - d_c}\right) + \frac{L_2 - d_c}{d} \text{ if } L_2 \geq d_c
\]

\[
\phi_4 = \ln\left(1 + \frac{d}{d - d_c}\right) + \frac{x_x - d_c}{d} = \ln\left(\frac{1}{1 - d_c}\right) + \frac{x_s - d_c}{d} \text{ if } x_x \geq d_c
\]

\[
\phi_5 = \ln\left(\frac{1}{1 - d_c}\right)
\]

For \( x_x = 0 \), \( \phi_4 = k/k' \) with modulus \( m = \sin \frac{\pi d}{2d} \).

Note: Use \( \phi_1 \) only when \( x_1 = 0 \).

Use \( \phi_5 \) only when \( x_x = 0 \) and \( d_c = 0 \).

Sheet 4 of Figure C4 is the flow diagram for the computation of cutoff effectiveness.

8. In the example problems of Part II, one may observe that the analysis of cutoffs by the method of fragments sometimes produces a technically troublesome result. Specifically, an increase in cutoff depth occasionally fails to produce a decrease in the upward gradient at the landside toe. After some investigation of this problem, we believe it stems from the low ratio of
cutoff depth to levee width in Fragment 3 of Figure C5. Such a ratio is significantly less than that for this type of fragment when used to analyze the weir structures for which it was developed. Harr (1962) concurred in our finding when we described this situation. A technically acceptable analysis of cutoffs is possible through the finite-element method (Bathe 1982) but only at a greater computational cost.

**Relief wells**

9. Sheet 5 of Figure C4 is a flow diagram for relief well calculations. For these calculations, an allowable head at the landside toe of the levee is determined based on the critical gradient at that location and a user-selected factor of safety. The program then determines those combinations of well spacing and penetration which satisfy the criterion that the head midway between wells is equal to the allowable head at the landside toe of the levee. The well penetrations examined in the program range from 25 to 100 percent and well spacings range from 25 to 300 ft.

10. Special mention is made of procedures used to calculate head losses in the wells and the uplift factors used to calculate heads in the line of wells. Head losses in a well consist of screen and filter entrance losses, friction losses in the screen and riser pipe, velocity losses, and elevation losses.

11. Screen and filter entrance losses are estimated from pumping tests on a 16-in.-diam wood stave-well screen with a 6-in. sand filter, as presented in Figure C6 (US Army Engineer Division, Huntsville (HND) 1986). This figure may give somewhat high values of loss for steel and plastic well screens in current use. However, entrance loss data were not available for those materials, and the use of Figure C6 should result in conservative values.

12. Friction losses in the well screen and riser pipe are calculated according to the Darcy-Weisbach formula as described in EM 1110-2-1602 (1980). The resistance coefficient in the formula is solved by the Colebrook-White equation, also taken from EM 1110-2-1602. The computer code for the solution of the Colebrook-White equation was obtained from WES (1973). That equation requires the input of an effective roughness parameter for the material comprising the well screen and riser pipe. The program has default values of the roughness parameter for stainless steel, galvanized and plastic pipe estimated from information given in EM 1110-2-1602. The user may enter other values if desired. In accordance with recommendations in Engineer Bulletin 55-11 (1955)
and HND (1986), one-half the screen length is used in computing friction losses in the well screen.

13. Velocity head losses are computed as velocity squared divided by two times the acceleration of gravity. Elevation head is taken as the height of well top above tailwater. No provision is made to estimate head losses from fountain flow out of the well top.

14. Calculations for the average head in the line of wells and the head midway between wells are accomplished using the formulas in Technical Memorandum 3-424 (WES 1956) and Engineer Bulletin 55-11 (1955). These formulas require inputs of uplift factors which are scaled from a nomograph shown in both references. A computer solution to the nomograph was obtained from Conroy (1984) and is incorporated in the program. Conroy (1984) has indicated that the computer solution may diverge somewhat from values of uplift factors estimated from the nomograph for values of \( D/a \) less than 0.3 and greater than 4.0, where \( D \) is the effective thickness of the pervious foundation and 'a' is the well spacing, but this was not significant for practical well spacings.

15. For the special case of no landside top stratum, the above-described procedure for well analysis is not valid since there is a no landside blanket through which to calculate an allowable head. However, it is sometimes desired to channel a portion of the levee underseepage into a well system so as to cut down on uncontrolled flow and to lessen the chances for development of piping or sand boils (WES 1956). The program provides for the analysis of a well system in this special case of no landside top stratum. The user selects the percentage reduction in levee underseepage which will be intercepted by the well system. The program then calculates the required spacings of wells for different depths of penetration, such that the well discharge per 100 ft of levee equals the desired reduction in underseepage flow.

16. For each selected combination of well spacing and penetration that satisfies the design criteria, the cost of the well system per 100 ft of levee is calculated; the program identifies the least cost combination of penetration and well spacing. Elements included in the cost are drilling through the top stratum and pervious foundation and cost of well screen and riser pipe and filter, all of which are on a per foot basis. Lump sum costs include backfilling, well cover, and well development and testing. Options are provided for the user to select well screens and riser pipes of stainless steel, galvanized steel, and plastic.
Cost Summary

17. A summary of the costs for the construction of landside berms, riverside blanket, cutoff wall, or line of relief wells to control levee underseepage is printed on a single page (sheet 6 of Figure C4). For the case of relief wells, the least cost combination of penetration and well spacing per 100 ft of levee is shown.
PART II: COMPARISON OF COMPUTER RESULTS WITH HAND CALCULATIONS

18. Hand calculations and computer runs were made for seven levee cross sections to determine if the computer program can correctly calculate substratum pressure, hydraulic gradient and seepage flow at and under a levee, and the dimensions of berms and riverside blankets, depths of cutoffs, and spacing and depth of relief wells to reduce substratum pressure to levels required by specified criteria. These computations are shown in Appendix E. For each cross section, the hand calculations are shown first, and these are followed by the computer printout sheets for the identical calculations. Hand calculation results are hand written on the computer printout sheets for direct comparison.

Description of Cross Sections

19. Although the seven levee cross sections chosen to test the computer program's capability do not represent all possible conditions that might be encountered in the field, they do represent a broad cross section of conditions that might be encountered. The principal variables in the cross sections used were the type of top stratum, thickness of pervious substratum, and the entrance and exit seepage conditions. The first levee section (cross section 1) is for a condition of no top stratum. The second levee section (cross section 2) is for a condition with impervious top stratum on both the riverside and landside of the levee. The third levee section (cross section 3) is for a condition with pervious top stratum limited on the riverside but infinite in extent on the landside. The fourth levee section (cross section 4) is for a condition with pervious top stratum limited on both the riverside and landside and with an open exit. The fifth levee section (cross section 5) was taken from the Stovall, Mississippi, Levee Station 77/38+00; the geological cross section is shown, and the procedure used to develop a schematic section for analysis has been described. This section represents a condition for an open borrow pit on the riverside and a blocked seepage exit on the landside. Piezometer data from the Stovall section have also been computer analyzed and results are shown on a computer-prepared cross section.

20. The sixth levee section (cross section 6) is for a condition with a top stratum similar to cross section 3 but the pervious substratum is
nonuniform and nonisotropic (only relief well calculations were made for this cross section). The seventh levee section (cross section 7) was taken from Sny Island Levee Drainage District, Range SA, Station 1153+52 (Cunny 1980), except that the levee height was increased by 5 ft; the soil profile is shown and the reasoning used to develop a schematic section for analysis has been described. Calculations for cross section 7 include a berm using Rock Island procedures, a sand berm using standard Corps procedures, and cutoff and relief well calculations.

Evaluation of Computer Results

General

21. Details of the hand calculations are shown for each cross section. Results of the hand calculations are summarized on computer printout sheets which also include the results of the computer calculations. Cost data for each of the control measures is shown for both computer and hand calculations. Cost data for the Stovall section (cross section 5) are also summarized and costs for alternate control measures are readily compared. Also shown are computer directed plots to demonstrate the computer capability to produce levee cross sections with no control measures; with piezometer data; and with berm, blanket, cutoff and/or relief well control measures.

22. As may be noted, the comparison between hand calculated and computer calculated data is excellent for berm, blanket, and cutoff control measures, the differences always being explainable as roundoff differences. However, some explanation is needed to assist in the evaluation of the comparison of hand and computer relief well calculations.

Analysis of relief well differences

23. Relief well hand calculations for cross sections 1 through 5 and 7 were made using the procedures in Technical Memorandum 3-424 (WES 1956). This includes the nomograph shown in Figure C7 for determination of uplift factors $\theta_{av}$ and $\theta_{m}$, and the simple chart for determination of head loss in Figure C8. However, hand calculations for the sixth cross section were made using mathematical formulas for determining the uplift factors $\theta_{av}$ and $\theta_{m}$, and the technically more accurate equation for determining head loss as described in the previous section.
24. As noted on the printout sheet for the sixth cross section, the comparison of the computer results with the hand calculations for relief wells is excellent, the differences being easily explained by random roundoff errors. For the other cross sections, however, the difference between computer results and hand calculations are systematic and needed further study.

25. Except for relief well penetrations of 25 percent for cross sections 1 and 7, the difference between computer and hand calculations for cross sections 1 through 4 and 7 follow a pattern such that at low penetration computer results compared favorably with hand calculations, whereas at deeper penetration, hand calculations indicated the need for closer well spacing. For cross section 5, however, computer results indicated a need for significantly closer well spacing for each of the penetrations for which hand calculations were made.

26. Computer calculations for the uplift factors $\theta_{av}$ and $\theta_m$ were examined to determine if this could be a source of the difficulty. Generally it was found that the agreement between computer calculated $\theta_{av}$ and $\theta_m$ and that determined by reading the nomograph of Figure C7 was very good, the differences being about 1 percent. The only times when the differences became significant were at the extreme ends of the range of $D/a$ values for $\theta_{av}$. When the $D/a$ values were less than 0.3 or greater than 4, the differences were as much as 11 and 22 percent, respectively. This could explain the difficulty with the 25 percent penetrations for cross sections 1 and 7 where the $D/a$ values were 4.4 and 2.2, respectively; a 3 percent difference in $\theta_{av}$ could result in a 15 percent difference in well spacing and this is what was calculated. However, these differences at the extreme values of $D/a$ could not explain the difference in calculated well spacing for other calculated conditions.

27. When head losses were examined, it readily became apparent that the differences in required well spacing were because of the more realistic expressions being used by the computer for calculating entrance and friction head losses. For cross section 5 where the pervious foundation is 40 ft and the well screen short, the entrance head losses are significantly higher than those indicated by the chart of Figure C8. For example, with a 10-ft well screen for 25 percent penetration, the computer-calculated total head loss is 2.4 ft, whereas that indicated by Figure C8 for a well flow of 467 gpm is 1.05 ft, the difference being caused largely by calculated entrance loss.
cross sections 1 through 4 where the pervious foundation is 100 ft and the well screen longer (and in addition it is assumed that the screen is made out of plastic rather than wood), the entrance and friction losses calculated by the compute will be less than those indicated in Figure C8. For example, with a 100-ft well screen and a flow of 600 gpm, the computer would calculate a head loss of about 1.1 ft, whereas Figure C8 would indicate a head loss of about 1.3 ft. Thus, it appears that differences in well spacings for cross sections 1 through 5 and 7 can be largely explained by differences in computer-calculated head loss and those determined from the chart in computer-calculated head losses and those determined from the chart in Figure C8. The computer-calculated head losses are known to be technically more accurate than those determined from Figure C8; therefore, the computer-calculated well spacings are considered to be technically superior, an improvement made possible by the use of the computer program.

Cost Comparisons

28. Costs calculated for the various control measures indicate that for the cross sections studied the cost per 100 ft of levee for berms ranged from $1,950 to $59,300; for riverside blankets from $12,800 to $66,700; for cutoffs from $15,600 to $55,500; for relief wells from $3,050 to $11,600 at penetrations ranging from 0.375 to 0.75. Based on initial costs, relief wells were generally the least costly control measure, but maintenance costs, depth of the pervious stratum, and other factors will also significantly influence the choice of control measure for any particular situation.
Figure 1. Levee Underseepage Main Menu
Figure 2. Input Data Menu (Sheet 1 of 3)
ALL INPUT SUBROUTINES

Start ROUTINE

Get Input Data from File

Data File Exists?

Yes

Write Input Data to File

Yes

Save Input to File?

Yes

Display Input Data to Screen

End Routine

No

Get Input Data from User

No

Figure 2. Input Data Menu (Sheet 2 of 3)
CONTROL MEASURE UNIT COST MENU

Start
CONCOST

Print
Control
Measure
Unit Cost
Menu

Choose
Option

Berm

Riverside
Blanket

Cutoff

Relief
Well

Return
to Input
Menu

Figure 2. Input Data Menu (Sheet 3 of 3)
Figure 3. Gradient and Seepage Calculations Menu (Sheet 1 of 4)
SUBROUTINE INITIAL CONDITIONS

Figure 3. Gradient and Seepage Calculations Menu (Sheet 2 of 4)

C17
SUBROUTINE FROM PIEZOMETER DATA

Start
CALCPZ

All
Inputs in
Memory?

Yes
Input
Date of
Reading

Find Two
Substratum
Heads and
Piezometer
Distances

Calculate
Seepage
Initial
Conditions

Print
Output
Draw Graph
Save Output
Data to
File

No
Print
Inputs
not in
Memory

Return
to
Seepage
Menu

Figure 3. Gradient and Seepage Calculations
Menu (Sheet 3 of 4)
Figure 3. Gradient and Seepage Calculations Menu (Sheet 4 of 4)
Figure 4. Control Measure and Cost Menu (Sheet 1 of 6)
SUBROUTINE BERM

Start BERM

All Required Inputs in Memory?

Yes

Input Min & Max Berm Widths

Choose from:
1. Impervious berm
2. Semipervious berm
3. Pervious berm w/ collector pipe
4. Sand berm
5. Rock Island berm

Choose Between Nine Cases. Calculate Berm and Cost

Cases 2, 4, and 9

Print Output Draw Graph and Save Output to File

Return to Control Measure Menu

Cases 6, 7, and 8

Calculate Riverside Blanket

Q_s > 200

Print Inputs not in Memory

Figure 4. Control Measure and Cost Menu (Sheet 2 of 6)
SUBROUTINE RIVERSIDE BLANKET

Start BLANKET

All Required Inputs in Memory

Yes

Choose from: 1. Uniform Thickness 2. Triangular Section

Choose from Two Cases & Calculate Blanket and Cost

Choose from Two Cases with Borrow Pits & Compute Blanket and Cost

No

Borrow Pit Exists?

Yes

Print Output Draw Graphs & Save Data to File

Print Inputs Not in Memory

Return to Control Measure Menu

Choose from: 1. Uniform Thickness 2. Triangular Section

Case 1 $z_{br} = 0$

$L1 = 0$

Figure 4. Control Measure and Cost Menu (Sheet 3 of 6)
SUBROUTINE CUTOFF

[Diagram of flowchart starting with "Start CUTOFF" and proceeding with decision points: "All Required Inputs in Memory?" Yes leads to "Input dc/d for Cutoff Calculation" and then "Calculate Effects of Cutoff on Seepage & Cutoff Cost" and finally "Print Output Draw Graph & Save Output to File" and "Return to Control Measure Menu". No leads to "Print Inputs Not in Memory".]

Figure 4. Control Measure and Cost Menu
(Sheet 4 of 6)

C23
SUBROUTINE WELL

Start
WELL

All
Required
Input in
Memory?

Yes

Input
Depths &
Permeabilities
in Pervious
Foundation

Calculate
Asel, Wbar, Qw,
and Cost for Each P
Determine Minimum
Cost

Print Output
Draw Graph
& Save
Output to
File

Return to Control
Measure
Menu

Figure 4. Control Measure and Cost Menu
(Sheet 5 of 6)
Figure 4. Control Measure and Cost Menu
(Sheet 6 of 6)
Figure 5. Schematic for analysis of cutoff by method of fragments
Figure 6. Entrance head loss (HND 1986)
EXAMPLE:
Where: \(a/r_w = 100, \theta_{QV} = 1.0, \theta^* = 1.0\)
Step 1. Locate \(\theta_{QV} = 1.0\) on \(a/r_w\) line = 100 and mark point
Step 2. Locate \(D/a \times 1.0\) on \(D/a\) line for \(\theta_{QV}\)
Step 3. Place triangle edge on above points located by steps 1 and 2.
Step 4. Slide triangle parallel to initial position to point \(D/a = 1.00\) on \(D/a\) line for \(\theta_m\)
Step 5. Read off value of \(\theta_m\) on \(a/r_w\) line = 100, \(\theta_m = 1.05\)
Step 6. Slide triangle parallel to initial position to pole point on \(D/a\) line of \(\theta_{QV}\)
Step 7. Read off percent screen penetration = 46% on \(a/r_w = 1000\)

Figure 7. Nomographic chart for design of relief well systems (WES 1956)
Figure 8. Hydraulic head losses in 8-in. ID wood-stave well with 6-in. gravel filter (WES 1956)
APPENDIX D: DEFAULT UNIT COSTS

BERM UNIT COSTS

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (CU YD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNSPECIFIED BERM</td>
<td>$1.30</td>
</tr>
<tr>
<td>IMPERVIOUS BERM</td>
<td>$1.30</td>
</tr>
<tr>
<td>SEMIPERVIOUS BERM</td>
<td>$1.30</td>
</tr>
<tr>
<td>SAND BERM</td>
<td>$3.75</td>
</tr>
<tr>
<td>PERVIOUS BERM W/ COLL. PIPE, UNDEFINED</td>
<td>$3.75</td>
</tr>
<tr>
<td>ROCK ISLAND BERM</td>
<td>$3.75</td>
</tr>
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</table>

BLANKET UNIT COST

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<th>Description</th>
<th>Cost (CU YD)</th>
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</thead>
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</tbody>
</table>

CUTTOFF UNIT COSTS

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<tr>
<td>2</td>
<td>$8.00</td>
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RELIEF WELL UNIT COSTS

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<th>Description</th>
<th>Cost (FT)</th>
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<tbody>
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</tr>
<tr>
<td>DRP</td>
<td>$16.00</td>
</tr>
<tr>
<td>RP</td>
<td>$30.00    (PLASTIC PIPE 8 IN. DIA.)</td>
</tr>
<tr>
<td>WS</td>
<td>$85.00    (PLASTIC SCREEN 8 IN. DIA.)</td>
</tr>
<tr>
<td>FL</td>
<td>$12.00</td>
</tr>
<tr>
<td>BF</td>
<td>$400.00</td>
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<tr>
<td>WC</td>
<td>$300.00</td>
</tr>
<tr>
<td>WD</td>
<td>$1000.00</td>
</tr>
</tbody>
</table>
APPENDIX E: HAND CALCULATIONS AND COMPUTER PRINTOUTS

CONTENTS

CROSS SECTION 1: NO TOP STRATUM ............................................. E3
   Hand Calculations .................................................... E4
   LEVSEEP Calculations .............................................. E18

CROSS SECTION 2: IMPERVIOUS LANDSIDE AND RIVERSIDE TOP STRATA ........ E27
   Hand Calculations .................................................... E28
   LEVSEEP Calculations .............................................. E47

CROSS SECTION 3: PERVIOUS TOP STRATUM WITH INFINITE EXIT AND OPEN
   ENTRANCE ........................................................................ E55
   Hand Calculations .................................................... E56
   LEVSEEP Calculations .............................................. E77

CROSS SECTION 4: PERVIOUS TOP STRATUM WITH OPEN ENTRANCE AND EXIT ...... E93
   Hand Calculations .................................................... E94
   LEVSEEP Calculations .............................................. E112

CROSS SECTION 5: STOVALL, MISS., PERVIOUS LANDSIDE AND RIVERSIDE TOP
   STRATA WITH OPEN ENTRANCE AND BLOCKED EXIT ....................... E123
   Hand Calculations .................................................... E124
   LEVSEEP Calculations .............................................. E146
   Analysis of Piezometer Data........................................... E159

CROSS SECTION 6: WELL ANALYSIS FOR THREE LAYER FOUNDATION WITH TOP
   STRATA AND OPEN ENTRANCE AND EXIT CONDITIONS ................. E165
   Hand Calculations .................................................... E166
   LEVSEEP Calculations .............................................. E175

CROSS SECTION 7: ROCK ISLAND EXAMPLE .................................... E131
   Hand Calculations .................................................... E182
   LEVSEEP Calculations .............................................. E196
Cross Section 1
No top stratum: Case 1

\[ H = 25 \text{ ft} \]
\[ D = 100 \text{ ft} \]
\[ k_f = 1000 \times 10^{-4} \text{ cm/sec} \]
\[ k_h = 2 \times 10^{-4} \text{ cm/sec} \]
\[ L = 220 \text{ ft} \]
\[ L_1 = L_2 = 2 L_3 = 2 x_e = 2 x_f = 0 \]

\[ D = (\Sigma D k_f x / k_h) \]
\[ = D (k_f / k_h)^{1/2} = 100 (2)^{1/2} = 141 \text{ ft} \]

**Initial condition calculations**

Since \( L_0 = 0 \)
\[ x_1 = 0 \]
\[ x_3 = 0 \]

\[ M = \frac{H}{x_1 + L_2 + x_3} = \frac{25}{10 + 220 + 0} = 0.113 \text{ ft} \]

\[ i = \frac{h_0}{2 x} \]

\[ Q_3 = \frac{1472 k_h \times H \times D}{L_2 + 0.86 D} = \frac{1472 \times 1000 \times 10^{-4} \times 141}{220 + 0.86 (141)} 
= 1520 \text{ gpm} / 100 \text{ ft}^2 \text{ of levee section} \]
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. I by RGC

Date 4/30/77
Page 2 of 14

Bern analysis

Because $Ero = 20$, Bern width is based on hand's Creep Ratio, $Cu$

For fine sand, $Cu = 7.0$

$$K = \frac{3\, Cu\, H - L_2}{3\, (7\, (25)) - 220} = \frac{305\, ft}{3}$$

$$t = 1.25 \left( \frac{h_0}{1.20} \right) \text{ where } h_0 = \frac{H \left( L_2 + 0.865 \right)}{L_2 + 8 + 0.865}$$

$$t = 1.25 \left( \frac{16.5}{1 + 0.3} \right) = 15.9\, ft$$

$$h_{min} = \frac{t - 2}{K - 2/\, m^3} = \frac{15.9 - 2}{305 - 2/0.25} = 0.047 > 0.02 = 0.4\, ft$$

check $h_{10} = \frac{h_{min}}{0.45 - 0.047} = 19.6 < 14.25 = 0.4\, ft$

$$V_B = \left[ \frac{2 \left( \frac{2}{m^3} \right) + \frac{t + 2}{2} \left( K - \left( \frac{2}{m^3} \right) \right) + \frac{t^2}{2(m_{10} - m_{10})} \right] \frac{100}{27}$$

$$= \left[ \frac{2 \left( \frac{2}{0.25} \right) + (15.9 + 2) \left( 305 - 2/0.25 \right) + \frac{15.9^2}{2(0.15 - 0.047)} \right] \frac{100}{27}$$

$$= 12,180\, yd^2 / 100\, ft^3 = \text{levee station}$$

$$Q_5 = \frac{14.72 \times 6\times H \cdot D}{L_2 + 8 + 0.86\, D} = \frac{14.72 \times 1000 \times 10^{-4} \times 25 \times 141}{220 + 305 + 0.86(141)}$$

$$Q_5 = 503\, gpm / 100\, ft^3 = \text{levee station}$$

Because $Q_5 > 200\, gpm / 100\, ft^3$, a Riverside blanket is required.
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 1 by RWC

Date 4/30/67

Page 3 of 14

Riverside blanket analysis: uniform section

\[ x_{nq} = \frac{1472 \times \beta}{H^2} - \frac{Q_{x_{nq}} (L_x + 1.0 + 0.43 \times 0.9)}{Q_{x_{nq}}} \]

\[ = \frac{1472 \times 1000 \times 10^{-4} \times 15 \times 141 - 200 (220 + 3.35 + 0.43(141))}{200} \]

= 2010 ft - seepage entrance is open

1. \[ x_{nq} \text{ also } = \frac{\tanh (C_b \times L_{Bq})}{C_b} \text{ where } C_b = \left( \frac{k_b}{2 \times \beta H^2} \right)^{\frac{1}{2}} \]

Note: \( k_b \) and \( C_b \) must be selected so that \( (C_b)(x_{nq}) < 1 \).

Choose \( C_b = 3 \text{ ft} \) and \( k_b = 0.01 \times 10^{-4} \text{ cm/sec (compacted lean clay)} \)

\[ C_b = \left( \frac{0.01 \times 10^{-4}}{3 \times 1000 \times 10^{-4} \times 141} \right)^{\frac{1}{2}} = 0.0001537 \]

check \( (C_b)(x_{nq}) = 0.0001537 \times 2010 = 0.309 < 1 \)

\[ \tanh^{-1} ((C_b)(x_{nq})) = \frac{C_b \times L_{Bq}}{2} \]

\[ L_{Bq} = \frac{\tanh^{-1} (0.309)}{0.0001537} = \frac{0.314}{0.0001537} = \frac{20.50 \text{ ft}}{3} \]

\[ V_{Bq} = (L_{Bq} \times 2q)^{100 \times 27} = 23.100 \text{ yd}^3 / 100 \text{ ft levee station} \]

Cost for Berm and Uniform Riverside Blanket

Berm: \[ \text{Cost} = V_{Bq} \times \text{Unit cost} = 12,160 \times 1.30 = ¥15,800 \]

Blanket: \[ \text{Cost} = V_{Bq} \times \text{Unit cost} = 23,100 \times 1.30 = ¥29,730 \]

Total: \[ ¥43,530 \]
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 1 by KWC

Date 4/3/67
Page 4 of 14

Beam and Riverside Blanket Analysis (continued)

With Beam and Blanket

\[ x_1 = \frac{\text{tanh} \left( \frac{C_{B}}{C_{B}} \right)}{C_{B}} = \frac{\text{tanh} \left( 0.1 \cdot 0.00000057 \right)}{0.00000057} \]

\[ = \frac{2000 \text{ ft}}{} \]

\[ x_3, M_1, \text{ and } \text{undefined} \]

\[ Q_2 = \frac{14.72 \times \frac{L_3}{4} + \frac{D}{x_1 + L_3 + \frac{2}{x_1} + 0.43}}{2010 + 220 + 3.5 + 0.43(41)} \]

\[ = 200 \text{ qpm} / 100 \text{ ft levee station} \]
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 1 by \( \omega C_3/R_w C \)

Cut-off Analysis

\[ \Phi_1 = 0.43, \quad \Phi_2 = 0 \]

\[ \Phi_3 = \ln \left( \frac{1}{1 - \frac{d_c}{d'}} \right) + \frac{1}{\alpha} - \frac{d_c}{d'} = \ln \left( \frac{1}{1 - \frac{d_c}{d'}} \right) + 1.5\alpha - \frac{d_c}{d'} \]

<table>
<thead>
<tr>
<th>( \frac{d_c}{d'} )</th>
<th>( \frac{1}{1 - \frac{d_c}{d'}} )</th>
<th>( 1.5\alpha - \frac{d_c}{d'} )</th>
<th>( \Phi_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>2.0</td>
<td>1.04</td>
<td>1.753</td>
</tr>
<tr>
<td>0.6</td>
<td>2.5</td>
<td>0.96</td>
<td>1.816</td>
</tr>
<tr>
<td>0.7</td>
<td>3.33</td>
<td>0.86</td>
<td>2.043</td>
</tr>
<tr>
<td>0.8</td>
<td>5.0</td>
<td>0.76</td>
<td>2.349</td>
</tr>
<tr>
<td>0.9</td>
<td>10.0</td>
<td>0.66</td>
<td>2.963</td>
</tr>
<tr>
<td>0.95</td>
<td>20.0</td>
<td>0.61</td>
<td>3.606</td>
</tr>
</tbody>
</table>

\[ \Phi_4 = \frac{K}{K'} \] with modulus \( m = \sin \frac{\pi}{2} \frac{d_c}{d'} \)

<table>
<thead>
<tr>
<th>( \frac{d_c}{d'} )</th>
<th>( \frac{\pi}{2} \frac{d_c}{d'} )</th>
<th>( m^2 )</th>
<th>( (K/K')^* = \Phi_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>45°</td>
<td>0.500</td>
<td>1.00</td>
</tr>
<tr>
<td>0.6</td>
<td>54</td>
<td>0.654</td>
<td>1.154</td>
</tr>
<tr>
<td>0.7</td>
<td>63</td>
<td>0.794</td>
<td>1.55</td>
</tr>
<tr>
<td>0.8</td>
<td>72</td>
<td>0.904</td>
<td>1.61</td>
</tr>
<tr>
<td>0.9</td>
<td>81</td>
<td>0.975</td>
<td>2.05</td>
</tr>
<tr>
<td>0.95</td>
<td>86.5</td>
<td>0.994</td>
<td>2.51</td>
</tr>
</tbody>
</table>

\[ Q_S = \frac{1472 \frac{d_c}{d'} H}{\Phi_m} = \frac{1472 \times 1000 \times 10^{-4} \times 25}{\Phi_3 + \Phi_3 + \Phi_4} \]

<table>
<thead>
<tr>
<th>( \frac{d_c}{d'} )</th>
<th>( \sum \Phi_m )</th>
<th>( Q_S )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>3.183</td>
<td>115.6</td>
</tr>
<tr>
<td>0.6</td>
<td>3.440</td>
<td>106.4</td>
</tr>
<tr>
<td>0.7</td>
<td>3.843</td>
<td>95.8</td>
</tr>
<tr>
<td>0.8</td>
<td>4.409</td>
<td>85.5</td>
</tr>
<tr>
<td>0.9</td>
<td>5.443</td>
<td>67.6</td>
</tr>
<tr>
<td>0.95</td>
<td>6.546</td>
<td>52.2</td>
</tr>
</tbody>
</table>
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. ___ by wCS/RwE

Cutoff analysis (cm. ft)

\[ M = \frac{h_A - h_B}{L_2}; \quad h_A = H \left(1 - \frac{\Phi_i}{2\Phi_m}\right); \quad h_C = H \left(1 - \frac{\Phi_i + \Phi_3}{2\Phi_m}\right) \]

\[ h_B = h_A - \frac{L_2}{L_2 + d_c} (h_A - h_C) \]

<table>
<thead>
<tr>
<th>(d_c/d_i)</th>
<th>(\Phi_i/2\Phi_m)</th>
<th>(h_A)</th>
<th>(h_C)</th>
<th>(d_c)</th>
<th>(h_A - h_C)</th>
<th>(h_B)</th>
<th>(M = \frac{h_A - h_B}{220})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.1351</td>
<td>21.62</td>
<td>7.85</td>
<td>70.7</td>
<td>13.77</td>
<td>11.20</td>
<td>0.047</td>
</tr>
<tr>
<td>0.6</td>
<td>0.1243</td>
<td>21.89</td>
<td>8.34</td>
<td>84.8</td>
<td>13.55</td>
<td>12.11</td>
<td>0.044</td>
</tr>
<tr>
<td>0.7</td>
<td>0.1119</td>
<td>22.20</td>
<td>8.78</td>
<td>99.0</td>
<td>13.42</td>
<td>12.94</td>
<td>0.042</td>
</tr>
<tr>
<td>0.8</td>
<td>0.0975</td>
<td>22.52</td>
<td>9.13</td>
<td>113.6</td>
<td>13.43</td>
<td>13.69</td>
<td>0.040</td>
</tr>
<tr>
<td>0.9</td>
<td>0.0990</td>
<td>22.02</td>
<td>9.42</td>
<td>127.3</td>
<td>13.60</td>
<td>14.40</td>
<td>0.039</td>
</tr>
<tr>
<td>0.95</td>
<td>0.0947</td>
<td>23.35</td>
<td>9.58</td>
<td>134.3</td>
<td>13.77</td>
<td>14.60</td>
<td>0.039</td>
</tr>
</tbody>
</table>

\[ I_E = \frac{h_c \Pi}{2d_i K_m}; \quad \bar{i}_{avq} = \frac{h_c}{d_i} \]

<table>
<thead>
<tr>
<th>(d_c/d_i)</th>
<th>(m)</th>
<th>(m^2)</th>
<th>(K)</th>
<th>(i_E)</th>
<th>(\bar{i}_{avq})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.707</td>
<td>0.500</td>
<td>1.854</td>
<td>0.046</td>
<td>0.111</td>
</tr>
<tr>
<td>0.6</td>
<td>0.809</td>
<td>0.654</td>
<td>2.013</td>
<td>0.057</td>
<td>0.098</td>
</tr>
<tr>
<td>0.7</td>
<td>0.891</td>
<td>0.794</td>
<td>2.244</td>
<td>0.049</td>
<td>0.087</td>
</tr>
<tr>
<td>0.8</td>
<td>0.951</td>
<td>0.904</td>
<td>2.598</td>
<td>0.041</td>
<td>0.081</td>
</tr>
<tr>
<td>0.9</td>
<td>0.987</td>
<td>0.975</td>
<td>3.255</td>
<td>0.032</td>
<td>0.074</td>
</tr>
<tr>
<td>0.95</td>
<td>0.997</td>
<td>0.994</td>
<td>3.949</td>
<td>0.027</td>
<td>0.071</td>
</tr>
</tbody>
</table>

Cutoff Cost / 100 ft levee station, \(d_c/d_i = 0.95\)

\[ \delta_c + 2L = 0.95 \times 100 + 0 = 95\text{ ft} \]

Area @ \$3.50/ft² = 65 \times 100 = 6500\text{ ft}²

\[ \text{cost} = 6500 \times 3.50 = \$19500 \]

Area @ \$2.00/ft² = (95 - 65) \times 100 = 3000\text{ ft}²

\[ \text{cost} = 3000 \times 2.00 = \$6000 \]

Cutoff total cost = \$45,500 / 100 ft levee station

E9
Relief well analysis

No top stratum - special solution is required. Analysis will be based on percent of seepage tube intercepted by well system.

\[ H = 2.5 \text{ ft} \]
\[ L = 220 \text{ ft} \]
\[ r_w = 1 \text{ ft} \]
\[ T = 220 = 0 \]
\[ \frac{k_h}{k_v} = z \]
\[ k_h = 1000 \times 10^{-6} \text{ cm/sec} \]
\[ Q_w = \text{well flow} \]

Asel = selected well spacing

Transformed thickness of pervious stratum

\[ \bar{D} = D \left( \frac{k_h}{k_v} \right)^{1/2} = 100 (z)^{1/2} = 141 \text{ ft} \]

Flow without wells

\[ Q_5 = \frac{1472 k_h H \bar{D}}{S + \chi_3} \]

where \[ S = x_1 + L \]

\[ = 0.43 \bar{D} + L \]

\[ = 0.43 (141) + 220 = 281 \text{ ft} \]

\[ \chi_3 = 0.43 \bar{D} = 0.43 (141) = 61 \text{ ft} \]

\[ Q_5 = \frac{1472 (0.1) (25) (141)}{281 + 61} = 1520 \text{ gpm/100 ft of levee} \]

Let \( J = \) percent reduction in seepage = 60 \%

\[ Q_w \text{ desired} = \left( 1 - \frac{J}{100} \right) Q_5 \frac{\text{Asel}}{100} \]

\[ = \left( 1 - \frac{60}{100} \right) (1520) \frac{\text{Asel}}{100} = 6.07 \text{ Asel} \]
Relief well analysis (cont.)

P = 0.25

1st trial well spacing, a = 25 ft

Q_{w,des} = 6.07 \ a = 6.07 (25) = 152.7 \ m^3/min

Now calculate Q_{w} for a = 25 ft

\[ h = H - H_w \left( \frac{S + x_3}{x_3} \right) = 25 - 0.52 \left( \frac{251 + 61}{61} \right) = 22.08 \ ft \]

\[ h_{av} = \frac{h \ \Theta_{av}}{S + \frac{x_3 (S + x_3)}{x_3} \ \Theta_{av}} \]

where \( \Theta_{av} \) is obtained from Fig 60 of TM 3-424 for \( a/H_w = 25 \) and \( \delta/\alpha = 14/65 \approx 0.22 \); \( \Theta_{av} = 2.70 \)

\[ \frac{2.08 (2.70)}{25 + \left( \frac{251 + 61}{61} \right)} = 2.26 \ ft \]

\[ H_{av} = h_{av} + H_w = 2.26 + 0.52 = 2.78 \ ft \]

\[ Q_{w} = \frac{H - H_{av} - H_{av}}{S + x_3} \]

\[ Q_w = 14.72 \ \Delta M \ \eta \ \Delta \delta = 14.72 (25) (0.0375) (0.1)(141) = 174 \ m^3/min \]

compare \( Q_w = 174 \) with \( Q_{w,des} = 152 \)

2nd trial well spacing, a = 50 ft

Q_{w,des} = 6.07 \ a = 6.07 (50) = 303 \ m^3/min

\[ H_w = 0.75 \text{ from Fig. 61} \]

\[ h = H - H_w \left( \frac{S + x_3}{x_3} \right) = 25 - 0.75 \left( \frac{251 + 61}{61} \right) = 20.80 \ ft \]

\[ h_{av} = \frac{h \ \Theta_{av}}{S + \frac{x_3 (S + x_3)}{x_3} \ \Theta_{av}} \]

\( \Theta_{av} \) from Fig 60 of TM 3-424 for \( a/H_w = 50 \); \( \delta/\alpha = 2.82 \)

\[ \Theta_{av} = 2.25 \]

\[ \frac{20.80 (2.25)}{50 + \left( \frac{251 + 61}{61} \right)(2.25)} = 2.57 \ ft \]
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 1 by RWC

Levee Underseepage

Relief well analysis (cm³)

\[ P = 0.25 \quad \text{2nd trial well spacing,} \quad a = \text{50 ft (cm'd)} \]

\[ H_{av} = H_{aw} + H_{w} = 2.57 + 0.75 = 3.32 \text{ ft} \]

\[ \Delta M = \frac{H_{aw} - H_{w}}{x_3} = \frac{25 - 3.32}{251} = 0.0278 \]

\[ Q_w = 14.72 \text{ a} \Delta M \rho_f \frac{D}{g} = 14.72 \times (0.0278)(0.1)(141) = 2.36 \text{ gpm} \]

\[ \text{Compare} \quad Q_w = 2.36 \quad \text{with} \quad Q_{des} = 5.03 \]

Interpolate for \( a_{sel} \)

<table>
<thead>
<tr>
<th>( a )</th>
<th>( Q_{des} )</th>
<th>( Q_w )</th>
<th>( Q_{des} - Q_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>162</td>
<td>187</td>
<td>-25</td>
</tr>
<tr>
<td>50</td>
<td>303</td>
<td>236</td>
<td>+67</td>
</tr>
</tbody>
</table>

\[ a_{sel} = 25 + 25 \times \left( \frac{25}{25 + 67} \right) = 32.5 \text{ ft} \]

\[ Q_w = 177 + (236 - 177)(25/67) = 194 \text{ gpm} \]

\[ \bar{w} = PD = 0.25(100) = 25 \text{ ft} \]

Cost per well (using plastic pipe and screen)

\[ C_W = (D_{P} + R_{P}) \times 25 + (D_{S} + W_{S} + F_{L}) \bar{w} + B_{S} + W_{C} + W_{D} \]

\[ = (20 + 50) \times 0 + (16 + 85 + 12) \times 25 + 400 + 300 + 1000 = 4,525 \]

Cost per 100 ft of levee station

\[ C_{WS} = C_W \times \left( \frac{100}{a_{sel}} \right) = \frac{4,525}{16} \times \frac{100}{32} = 14,140/100 \text{ ft} \]

\[ P = 0.375 \quad \text{1st trial well spacing,} \quad a = \text{50 ft} \]

\[ Q_{wde} = 6.07 \times 2 = 6.07 \times 50 = 303 \text{ gpm} \]

\[ H_{w} = 0.75 \text{ from fig. 41} \]

\[ h = 14.72 \times \frac{5 + x_2}{x_3} = 25 \times 0.75 \times \frac{251 + 61}{61} = 20.80 \text{ ft} \]

\[ h_{aw} = \frac{h \Theta_{aw}}{\frac{3}{2} + (\frac{5 + x_2}{x_3}) \Theta_{aw}} \quad \Theta_{aw} \text{ from fig. 63,} \quad a_{/w} = 50, \quad \bar{w} = 2.82 \]

\[ \Theta_{aw} = 1.41 \]
Relief well analysis: $P = 0.375$, 2nd trial well spacing, $a = 75$ ft (cont)

\[ h_{av} = 20.4 \left( 1.41 \right) = 2.17 \text{ ft} \]
\[ h_{aw} = \frac{2.97 + (2.81 + 0.1)(1.41)}{61} \]
\[ H_{aw} = h_{aw} + H_w = 2.17 + 0.75 = 2.92 \text{ ft} \]

\[ \Delta M = \frac{H - H_{aw} - H_w}{5} = \frac{25 - 2.92 - 2.92}{61} = 0.0307 \]

\[ Q_w = 14.72 \text{ a DM} \]

\[ \overline{Q} = 14.72(50)(0.0307)(0.1)(141) = 319 \text{ gpm} \]

compare $Q_w = 319$ with $Q_{wdes} = 303$

Increase $a$ for 2nd trial well spacing, $a = 75$ ft

\[ Q_{wdes} = 6.07 a = 6.07(75) = 455 \text{ gpm} \]

\[ H_w = 1.02 \text{ ft} \text{ from Fig. 61} \]
\[ h = H - H_w \left( \frac{3 + x^2}{x^2} \right) = 25 - 1.02 \left( \frac{2.81 + 0.1}{61} \right) = 19.28 \text{ ft} \]
\[ h_{aw} = \frac{h \Theta_{aw}}{2} + \left( \frac{3 + x^2}{x^2} \right) \Theta_{aw} \]
where $\Theta_{aw}$ is from Fig. 60 for $r_{aw} = 2.5$
\[ \frac{2.97 + (2.81 + 0.1)(1.41)}{61} \]
\[ \frac{2.97 + (2.81 + 0.1)(1.41)}{61} = 2.29 \text{ ft} \]
\[ H_{aw} = h_{aw} + H_w = 2.29 + 1.02 = 3.31 \text{ ft} \]

\[ \Delta M = \frac{H - H_{aw} - H_w}{5} = \frac{25 - 3.31 - 3.31}{61} = 0.02293 \]

\[ Q_w = 14.72 \text{ a DM} \]

\[ \overline{Q} = 14.72(72)(0.02293)(0.1)(141) = 357 \text{ gpm} \]

compare $Q_w = 357$ with $Q_{wdes} = 455$

Interpolate for $a_{sel}$

<table>
<thead>
<tr>
<th>$a$</th>
<th>$Q_{wdes}$</th>
<th>$Q_w$</th>
<th>$Q_{wdes} - Q_w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>303</td>
<td>319</td>
<td>-16</td>
</tr>
<tr>
<td>75</td>
<td>455</td>
<td>357</td>
<td>+98</td>
</tr>
</tbody>
</table>

\[ a_{sel} = 50 + 25 \left( \frac{16}{16 + 98} \right) = 54.6 \text{ ft} \]

\[ Q_w = 319 + 36 \left( \frac{16}{114} \right) = 324 \text{ gpm} \]

\[ \overline{w} = PD = 0.375(100) = 37.5 \text{ ft} \]

E13
Relief well analysis \( P = 0.375 \) (cm'd)

Cost per well (plastic screen)
\[
CW = (D_{Rb} + W_{b} + D_{L}) \bar{w} + BF + WC + WD
\]
\[
= (16 + 6.5 + 12) 37.5 + 400 + 300 + 1000 = \$ 5937
\]

Cost per 100 ft of levee station
\[
CWS = CW (100/asec) = 5937 (100/54) = \$ 10,990/100 ft
\]

\( P = 0.50 \), 1st trial well spacing, \( a = 75 \) ft

\[
Q_{waes} = 0.07 a = 0.07 (75) = 455 \text{ qpm}
\]

\[
H_w = 1.02 \text{ ft} \quad \text{from Fig. 61}
\]

\[
h = H - H_w (\frac{S + X_2}{X_2}) = 25 - 1.02 \left( \frac{2.81 + 61}{61} \right) = 19.28 \text{ ft}
\]

\[
h_{av} = \frac{h \Theta_{av}}{a + (\frac{S + X_2}{X_2}) \Theta_{av} \Theta_{av} = 0.98}
\]

\[
= \frac{19.28 \Theta_{av} (0.98)}{2.81 + (\frac{2.81 + 61}{61}) 0.98} = 2.04 \text{ ft}
\]

\[
h_e = h_{av} + H_w = 2.04 + 1.02 = 3.06 \text{ ft}
\]

\[
\Delta M = \frac{H - H_w - h_{av}}{S} = \frac{25 - 3.06 - 0.98}{2.81} = 0.0279
\]

\[
Q_w = 14.72 a \Delta M \bar{D} = 14.72 (75)(0.0279)(0.1)(141) = 435 \text{ qpm}
\]

Compare \( Q_w = 435 \) with \( Q_{waes} = 455 \)

2nd trial well spacing, \( a = 70 \) ft

\[
Q_{waes} = 0.07 a = 0.07 (70) = 455 \text{ qpm}
\]

\[
H_w = 0.97 \text{ ft}
\]

\[
h = H - H_w (\frac{S + X_2}{X_2}) = 25 - 0.97 \left( \frac{2.81 + 61}{61} \right) = 19.56 \text{ ft}
\]
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 1 by RWG

Relief well analysis. P = 0.50, 2nd trial Q = 70 ft³/min

\[ h_{av} = \frac{\theta_{av} - \frac{3}{2} + \left( \frac{3 + x_2}{x_3} \right) \theta_{av}}{\frac{3}{2} + \left( \frac{3 + x_2}{x_3} \right) \theta_{av}} \]

\[ \theta_{av} = 0.97 \]

\[ = \frac{19.50 \times 0.97}{251 + (251 + 61)(0.97)} = 2.01 \text{ ft} \]

\[ H_{av} = h_{av} + H_w = 2.01 + 0.97 = 2.98 \text{ ft} \]

\[ \Delta H = \frac{H - H_{av} - H_w}{x_3} = \frac{25 - 2.98 - 2.98}{281} = 0.0295 \]

\[ Q_w = 14.72 \times \Delta H \times \frac{D}{2} = 14.72 (70)(0.0295)(0.1)(14) = 428.9 \text{ gpm} \]

Compare \( Q_w = 428 \) with \( Q_{wdes} = 415 \)

Interpolate for \( a_{sel} \)

<table>
<thead>
<tr>
<th>( a )</th>
<th>( Q_{wdes} )</th>
<th>( Q_w )</th>
<th>( Q_{wdes} - Q_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>425</td>
<td>428</td>
<td>-3</td>
</tr>
<tr>
<td>75</td>
<td>455</td>
<td>435</td>
<td>+20</td>
</tr>
</tbody>
</table>

\[ a_{sel} = 70 + 5 \left( \frac{3}{23} \right) = 71 \text{ ft} \]

\[ Q_w = 428 + 7 \left( \frac{3}{23} \right) = 429.5 \text{ gpm} \]

\[ \bar{w} = P D = 0.50(10) = 50 \text{ ft} \]

Cost per well (using plastic screen)

\[ C_w = (D R_p + W S + FL) \bar{w} + 3 F + W C + W D \]

\[ = (14 + 85 + 12)(50 + 400 + 300 + 100) = \$7350 / \text{well} \]

Cost per 100 ft of levee station

\[ C_{ws} = C_w (100 / a_{sel}) = \$7350 (100 / 71) = \$10350 / 100 \text{ ft} \]

E15
Levee Underseepage Computer Program

Hand Computations used for Verification Date 8/24/86
Cross Section No. I by___

Relief well analysis, P = 0.75

1st trial wall spacing, a = 75 ft

Qwdes = 6.07 a = 6.07(75) = 455 qpm

Hw = 1.02 ft from fig. 61

h = H - Hw (5 + x) = 25 - 1.02 (281 + 61) = 19.28 ft

\[
\text{hav} = \frac{h \Theta av}{\frac{3}{2} + \left(\frac{5 + x}{x}\right) \Theta av}
\]

\[
\Theta av \text{ from fig. 60 } a/Hw = 75, \ \frac{b}{x} = 1.88
\]

\[
= \frac{19.28 (0.59)}{281 + (281 + 61) 0.59} = 1.61 \text{ ft}
\]

Ham = hav + Hw = 1.61 + 1.02 = 2.63 ft

\[
\Delta M = \frac{H - \text{Ham} - \text{Hav}}{3}
\]

\[
= \frac{25 - 2.63 - 2.63}{281} = 0.0345
\]

Qw = 14.72 a(AM)^{0.5} = 14.72 (75)(0.0345)(0.1)(1.1) = 568 qpm

Compare Qw = 568 with Qwdes = 455 qpm

Increase a for 2nd trial wall spacing, use a = 100 ft

Qwdes = 6.07 a = 6.07 (100) = 607 qpm

Hw = 1.35 ft from fig. 61

h = H - Hw (5 + x) = 25 - 1.35 (281 + 61) = 17.43 ft

\[
\text{hav} = \frac{h \Theta av}{\frac{3}{2} + \left(\frac{5 + x}{x}\right) \Theta av}
\]

\[
\Theta av \text{ from fig. 60 } a/Hw = 100, \ \frac{b}{x} = 1.41
\]

\[
= \frac{17.43 (0.62)}{281 + (281 + 61) 0.62} = 1.72 \text{ ft}
\]

Ham = hav + Hw = 1.72 + 1.35 = 3.07 ft
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 1 by IWC

Relief well analysis \( P = 0.75 \) (cont'd)

2nd trial well spacing \( a = 105 \) ft (cont'd)

\[
\Delta M = \frac{H - H_{av} - H_{av}}{K_3} = \frac{25 - 3.07 - 3.07}{281} = 0.0277
\]

\[
Q_w = 14.72 a \Delta M & 0 = 14.72 (100)(0.0277)(0.1)(141) = 578.9\text{ gpm}
\]

Compare \( Q_w = 578 \) with \( Q_{\text{well}} = 607 \)

Interpolate for \( a_{se} \)

<table>
<thead>
<tr>
<th>( a )</th>
<th>( Q_{\text{well}} )</th>
<th>( Q_w )</th>
<th>( Q_{\text{well}} - Q_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>455</td>
<td>568</td>
<td>-13</td>
</tr>
<tr>
<td>100</td>
<td>607</td>
<td>575</td>
<td>+32</td>
</tr>
</tbody>
</table>

\( a_{se} = 75 + 13 \left( \frac{100}{75} \right) = 82 \) ft

\( Q_w = 568 + 7 \left( \frac{13}{45} \right) = 570.9\text{ gpm} \)

\( D = P D = 0.75(100) = 75 \) ft

Cost per well (using plastic screen)

\[
C_W = (D R_p + W S + F L) \bar{u} + 12 F + W C + w D
\]

\[
z (16 + 45 + 12) 75 + 400 + 300 + 1000 = \$10,175
\]

Cost per 100 ft of levee station

\[
C_{WS} = C_W \left( \frac{100}{a_{se}} \right) = \$10,175 \left( \frac{100}{82} \right) = \$12,400/100\text{ ft}
\]

Summary

<table>
<thead>
<tr>
<th>( P )</th>
<th>( a_{se} )</th>
<th>( C_{WS} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>32.6 ft</td>
<td>$14,140</td>
</tr>
<tr>
<td>0.37</td>
<td>54</td>
<td>10,990</td>
</tr>
<tr>
<td>0.5</td>
<td>71</td>
<td>10,350</td>
</tr>
<tr>
<td>0.75</td>
<td>82</td>
<td>12,400</td>
</tr>
</tbody>
</table>

E17
PROJECT NAME: PROGRAM DEVELOPMENT
STATION: X-SECT. 1

GENERAL CONTROL MEASURE INPUT DATA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTE</td>
<td>165 FT</td>
</tr>
<tr>
<td>H</td>
<td>25 FT</td>
</tr>
<tr>
<td>LTO</td>
<td>120 FT</td>
</tr>
<tr>
<td>RTU</td>
<td>100 FT</td>
</tr>
<tr>
<td>L1</td>
<td>0 FT</td>
</tr>
<tr>
<td>L3</td>
<td>0 FT</td>
</tr>
<tr>
<td>ENTRANCE</td>
<td>UNDEFINED</td>
</tr>
<tr>
<td>EXIT</td>
<td>UNDEFINED</td>
</tr>
<tr>
<td>D</td>
<td>100 FT</td>
</tr>
<tr>
<td>DD</td>
<td>141 FT</td>
</tr>
<tr>
<td>ZBL</td>
<td>0 FT</td>
</tr>
<tr>
<td>KBL</td>
<td>0 CM/S</td>
</tr>
<tr>
<td>ZBR</td>
<td>0 FT</td>
</tr>
<tr>
<td>KBR</td>
<td>0 CM/S</td>
</tr>
<tr>
<td>ZT</td>
<td>0 FT</td>
</tr>
<tr>
<td>KF</td>
<td>0.1 CM/S</td>
</tr>
<tr>
<td>ZL</td>
<td>0 FT</td>
</tr>
<tr>
<td>SUBWT</td>
<td>50 LB/CU FT</td>
</tr>
</tbody>
</table>

SUPPLEMENTAL CONTROL MEASURE INPUT DATA

<table>
<thead>
<tr>
<th>BERM</th>
<th>RIVERSIDE BLANKET</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSB</td>
<td>IA</td>
</tr>
<tr>
<td>I0B</td>
<td>M3R</td>
</tr>
<tr>
<td>II</td>
<td>M4</td>
</tr>
<tr>
<td>M1</td>
<td></td>
</tr>
<tr>
<td>M3B</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUTOFF</td>
<td></td>
</tr>
<tr>
<td>NO SPECIAL INPUT REQUIRED</td>
<td>FSW = UNDEFINED</td>
</tr>
<tr>
<td>IOW</td>
<td>0.53</td>
</tr>
<tr>
<td>RW</td>
<td>1.0 FT</td>
</tr>
<tr>
<td>DP</td>
<td>0.67 FT</td>
</tr>
<tr>
<td>RUFF</td>
<td>0.0001</td>
</tr>
<tr>
<td>VISCOS</td>
<td>0.0000121 GAL*FT/SEC</td>
</tr>
<tr>
<td>J</td>
<td>60 %</td>
</tr>
<tr>
<td>HEL</td>
<td>0.33 FT</td>
</tr>
</tbody>
</table>

E18
PROJECT NAME: PROGRAM DEVELOPMENT
STATION: X-SECT. 1

LEVEE UNDERSEEPAGE ANALYSIS
INITIAL CONDITIONS

\[
\begin{array}{ll}
X_1 &= 0.0 \text{ FT} \\
X_3 &= 0.0 \text{ FT} \\
M &= 0.1136 \\
I &= 0.000 \\
Q_S &= 1522. \text{ GPM/100 FT} \\
H_0 &= 0.0 \text{ FT} \\
\$ &= 0.4132
\end{array}
\]
INIT ENDS

X3 = 0.

X1 = 0.

M = 1136.

I = 0.

Qe = 1522.
OUTPUT DATA FOR BERM ANALYSIS

Hand Calculations

\[ x_1 = 2012 \text{ FT} \]
\[ x_3 = \text{UNDEFINED} \]
\[ m = \text{UNDEFINED} \]
\[ i = \text{UNDEFINED} \]
\[ q_s = 200 \text{ GPM/100 FT} \]
\[ x = 305 \text{ FT} \]
\[ t = 15.9 \text{ FT} \]
\[ v_b = 12139 \text{ CU YD/100 FT LEVEE STATION} \]

RIVERSIDE BLANKET CALCULATED TO REDUCE UNDERSEEPEAGE

\[ x_{ro} = 2012 \text{ FT} \]
\[ l_{bo} = 2080 \text{ FT} \]
\[ v_{rbo} = 23107 \text{ CU YD/100 FT LEVEE STATION} \]
\[ k_b = 0.0001 \text{ CM/SEC} \]
\[ z_b = 3.00 \text{ FT} \]

IF \( x_{ro} \) OR \( l_{bo} \) DISTANCE TO RIVER, SOLUTION INFEASIBLE

BERM COST CALCULATION

\[ v_b = 12139 \text{ CU YD/100 FT LEVEE STATION} \]
\[ \text{UNIT COST} = \$ 1.30 /\text{CU YD} \]
\[ \text{TOTAL COST} = \$ 15781.00 /100 \text{ FT LEVEE STATION} \]

BLANKET COST CALCULATION

\[ v_{rbo} = 23107 \text{ CU YD/100 FT LEVEE STATION} \]
\[ \text{UNIT COST} = \$ 1.20 /\text{CU YD} \]
\[ \text{TOTAL COST} = \$ 27728.00 /100 \text{ FT LEVEE STATION} \]
OUTPUT DATA FOR CUTOFF ANALYSIS

\[
\begin{align*}
\text{DC/D} &= 0.950 \\
\text{X1} &= 0. \text{ FT} \\
\text{X3} &= 0. \text{ FT} \\
\text{M} &= 3.896 \times 10^{-1} \\
\text{I} &= \text{UNDEFINED} \\
\text{Qs} &= 563. \text{ GPM/100 FT} \\
\text{IAVG} &= 0.071 \\
\text{IE} &= 0.027
\end{align*}
\]

CUTOFF COST CALCULATION

\[
\begin{align*}
\text{DEPTH} &= 95. \text{ FT} \\
\text{COST} &= $ 43500.00 /100 \text{ FT OF LEVEE STATION}
\end{align*}
\]
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 1

OUTPUT DATA FOR RELIEF WELL ANALYSIS

<table>
<thead>
<tr>
<th>P</th>
<th>ASEL</th>
<th>WBAR</th>
<th>QW</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>.250</td>
<td>38.</td>
<td>32.</td>
<td>263.194</td>
<td>$ 11,912.00</td>
</tr>
<tr>
<td>.375</td>
<td>52.</td>
<td>38.</td>
<td>323.324</td>
<td>$ 11,310.00</td>
</tr>
<tr>
<td>.500</td>
<td>70.</td>
<td>50.</td>
<td>436.419</td>
<td>$ 10,452.00</td>
</tr>
<tr>
<td>.625</td>
<td>86.</td>
<td>63.</td>
<td>532.</td>
<td>$ 10,198.00</td>
</tr>
<tr>
<td>.750</td>
<td>100.</td>
<td>75.</td>
<td>607.570</td>
<td>$ 10,175.00</td>
</tr>
<tr>
<td>.875</td>
<td>109.</td>
<td>88.</td>
<td>674.</td>
<td>$ 10,603.00</td>
</tr>
<tr>
<td>1.000</td>
<td>117.</td>
<td>100.</td>
<td>723.</td>
<td>$ 11,080.00</td>
</tr>
</tbody>
</table>
| .750| 100. | 75.  | 607.   | $ 10,175.00  <= MINIMUM COST

Hand Calculations

X1 = 61. FT
X3 = 61. FT
QS = 1520. GAL/100 FT
J = 60. %
Cross Section 2
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 2 by RUC

Date 5/1/67
Page 1 of 19

Impervious riverside and landside top strata: Case 2

\[ L_3 + L_2 + L_1 \]

\[ Z \]

\[ H = 25 \text{ ft} \]
\[ Z_{Os} = 6 \text{ ft} \]
\[ k_{Os} = 0 \]
\[ i = 0.3 \]
\[ L_1 = 780 \text{ ft} \]
\[ Z_{Os} = 6 \text{ ft} \]
\[ k_{Os} = 0 \]
\[ L_1 = 0.8 \]
\[ L_2 = 220 \text{ ft} \]
\[ Z_{Os} = 6 \text{ ft} \]
\[ k_{Os} = 0 \]
\[ m = 0.25 \]
\[ L_3 = 500 \text{ ft} \]
\[ D = 100 \text{ ft} \]
\[ k_{Fe} = 1000 \times 10^{-4} \text{ cm/sec} \]

Open exit \[ L_{3} \]

Open entrance \[ L_{3} \]

Initial condition calculations

\[ M = \frac{H}{1 + L_2 + L_3} = \frac{25}{780 + 220 + 500} = 0.0167 \]

\[ i = \frac{h_0}{Z_{Os}} \text{ where } h_0 = \frac{H L_3}{L_1 + L_2 + L_3} \]

\[ i = \frac{8.3}{6.0} = 1.38 \]

\[ Q_5 = \frac{1472 k_{Fe} H D}{L_1 + L_2 + L_3} = \frac{1472 \times 1000 \times 10^{-4} \times 25 \times 100}{780 + 220 + 500} \]

\[ = 245 \text{ gpm/100 ft levee station} \]
Bern analysis

\[
\bar{x} = \frac{h_3 - h_2}{H} (L_1 + L_2 + L_3) \quad \text{where} \quad h_2 = 2.8, \quad L_2 = 0.8, 6 = 4.8 \text{ft}
\]

\[
= 500 - \frac{4.8}{25} (700 + 220 + 500)
\]

\[
= \frac{212 \text{ ft}}{}
\]

\[
x = 1.25 \left( \frac{h'_o - \bar{x}}{1 + h'_o} \right) \quad \text{where} \quad h'_o = h_o = 8.3 \text{ ft}
\]

\[
= 1.25 \left( \frac{8.3 - 0.3 (4)}{1 + 0.3} \right)
\]

\[
= \frac{6.3 \text{ ft}}{}
\]

\[
\text{check } m_2 = \frac{x - 2}{x - 8} = \frac{6.2 - 2}{212 - 8} = 0.021 > 0.02 \Rightarrow \text{ ok}
\]

\[
\text{check } h_b = \frac{m_3}{m_1 - m_2} = \frac{0.25 (6.3)}{0.25 - 0.021} = 6.9 \text{ ft} < H = 25 \Rightarrow \text{ ok}
\]
**Levee Underseepage Computer Program**

Hand Computations used for Verification  
Cross Section No. 2 by R. W. C.  

Date 5/10/65  
Page 3 of 19

### Bernoulli Analysis (cm't)

\[
V_B = \left[ 8 + \left( \frac{6.3 + 1}{2} \right) \left( \frac{6 \cdot 6}{2(0.25-0.021)} \right) + \frac{6.3}{2(0.25-0.021)} \right] \frac{100}{27} = 3490 \text{ yd}^3 / 100 \text{ ft levee station}
\]

\[
Q_S = \frac{1472 \times 100 \times 10^{-4} \times 25 \times 100}{L_1 + L_2 + L_3} = \frac{1472 \times 1000 \times 10^{-4} \times 25 \times 100}{780 + 220 + 500} \approx 245 \text{ qpm / 100 ft levee station}
\]

With Berns:

\[
x_1 = L_1 = 780 \text{ ft} \quad ; \quad x_2 = L_2 = 500 \text{ ft}
\]

\[
\lambda_{x_2} = \frac{h_2 - h}{x_2} = \frac{6.3 - 6.3}{6 + 6.3} = 0.16
\]

\[
W = \frac{14}{L_1 + L_2 + L_3} = \frac{25}{780 + 220 + 500} = 0.00147
\]

### Riverside Blanket Design

Since riverside top stratum is impervious, make \( L_2 = 1000 \text{ ft} \) and calculate width for additional blanket, \( x_2 \), such that \( \lambda_a = 0.7 \)

\[
x_a = x_2 \left( \frac{H}{h_a} - 1 \right) = L_2 \quad \text{where} \quad h_a = \lambda_a \times h
\]

\[
= 1000 \left( \frac{25}{4.2} - 1 \right) = 1475 \text{ ft}
\]

Entrance is open; \( x_a \) also \( = \tan \theta \times L_a \) \( \theta \) \( \frac{CR}{CR} \)

Choose \( L_a = 1.3 \times x_a = 1917 \text{ ft} \)
Levee Underseepage Compute Program

Hand Computations used for Verification
Cross Section No. 2 by RWC

Riverside blanket analysis (con't)

By trial and error, solve for \( C_B \)

\[
\begin{array}{cccccc}
C_B & x_C C_B & C_B L_B & \text{Tanch} C_B L_B & X_C C_B - \text{Tanch} C_B L_B \\
0.001 & 1.475 & 1.917 & 0.83 & 0.445 \\
0.0005 & 0.7375 & 0.9585 & 0.7436 & -0.0061 \\
0.00051 & 0.7375 & 0.97767 & 0.75206 & +0.00019 \text{ ok} \\
\end{array}
\]

\[ C_B = \left( \frac{k_B}{x_C C_B} \right)^{1/2} \]

\[ \frac{x_C}{k_B} = \frac{1}{C_B k_B P} = \frac{1}{0.00051 \times 1000 \times 10^{-4} \times 100} = 3.84,000 \]

choose \( k_B = 0.1 \times 10^{-4} \)

then \( x_B = 3.84,000 \times 0.1 \times 10^{-4} = 3.8 \) ft

with Riverside blanket

\[ \chi_1 = \frac{1475 \text{ ft}}{x_1} \]

\[ \chi_3 = \frac{500 \text{ ft}}{x_3} \]

\[ \lambda = \frac{h}{x} \quad \text{where} \quad h'' = \frac{H L_2}{x_1 + L_2 + L_3} = \frac{25 \times 500}{1475 + 1000 + 500} = 4.2 \text{ ft} \]

\[ M = \frac{H}{x_1 + L_2 + L_3} = \frac{25}{1475 + 1000 + 500} = 0.0034 \]

\[ Q_x = \frac{1475 \times k_B \times H \times P}{x_1 + L_2 + L_3} = \frac{1475 \times 0.1 \times 25 \times 100}{1475 + 1000 + 500} = 123 \text{ gpm } / 100 \text{ ft }\text{ of levee sta} \]

\[ V_{R3} = \frac{2 \times 30 \times 100}{25} = 3.8 \times 1517 \times 100 = 26,950 \quad \text{ft}^3 / 100 \text{ ft} \text{ of levee sta} \]

E31
Cutoff analysis

\[
\Phi_1 = \frac{L_1}{a}; \quad \Phi_2 = \ln \left( \frac{1}{1 - \Delta c/0} + \frac{L_1 - \Delta c}{D} \right);
\]

\[
\Phi_3 = \ln \left( \frac{1}{1 - \Delta c/0} + \frac{L_1 - \Delta c}{D} \right); \quad \frac{\Delta \Phi_m}{\Delta \Phi_m} = \Phi_1 + \Phi_2 + \Phi_3
\]

\[
\Phi_3 = \ln \left( \frac{1}{1 - \Delta c/0} + \frac{220}{100} - \frac{\Delta c}{D} \right); \quad \Phi_4 = \ln \left( \frac{1}{1 - \Delta c/0} + \frac{500}{100} - \frac{\Delta c}{D} \right)
\]

\[
Q_S = 2.85 \times 10^{-4} L/H = 7.8
\]

<table>
<thead>
<tr>
<th>$a/\Delta c$</th>
<th>$\Phi_1$</th>
<th>$\frac{1}{1-\Delta c/0}$</th>
<th>2.2 $a/\Delta c$</th>
<th>$\Phi_3$</th>
<th>$\Phi_4$</th>
<th>$\Delta \Phi_m$</th>
<th>$Q_S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>7.8</td>
<td>2.00</td>
<td>1.7</td>
<td>2.393</td>
<td>5.193</td>
<td>15.386</td>
<td>2.85</td>
</tr>
<tr>
<td>0.6</td>
<td>2.50</td>
<td>1.60</td>
<td>2.514</td>
<td>5.314</td>
<td>15.632</td>
<td>2.35</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>3.33</td>
<td>1.5</td>
<td>2.704</td>
<td>5.504</td>
<td>16.008</td>
<td>2.30</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>5.00</td>
<td>1.4</td>
<td>3.009</td>
<td>5.809</td>
<td>16.418</td>
<td>2.21</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>10.00</td>
<td>1.3</td>
<td>3.602</td>
<td>6.402</td>
<td>17.804</td>
<td>2.07</td>
<td></td>
</tr>
<tr>
<td>0.95</td>
<td>20.00</td>
<td>1.25</td>
<td>4.246</td>
<td>7.046</td>
<td>19.092</td>
<td>1.93</td>
<td></td>
</tr>
</tbody>
</table>

\[
h_A = H \left( 1 - \frac{\Phi_3}{\Delta \Phi_m} \right) = H \left( 1 - \frac{7.8}{\Delta \Phi_m} \right); \quad h_C = H \left( 1 - \frac{\Phi_2 + \Phi_3}{\Delta \Phi_m} \right) = H \left( 1 - \frac{7.8 + \Phi_3}{\Delta \Phi_m} \right)
\]

\[
h_B = h_A - \frac{L_2}{L_2 + \Delta c} (h_A - h_C) = h_A - \frac{220}{220 + \Delta c} (h_A - h_C)
\]

\[
h_D = h_C \left( 1 - \frac{\Delta c}{\Delta c + 250} \right) = h_C \left( 1 - \frac{\Delta c}{\Delta c + 500} \right); \quad \lambda = \frac{h_D}{\Delta \Phi_m}; \quad M = \frac{h_A - h_B}{L_2}
\]

\[
M = \frac{h_A - h_B}{220}
\]
**Levee Underseepage Computer Program**

Hand Computations used for Verification
Cross Section No. 2 by 

<table>
<thead>
<tr>
<th>$d_c/o$</th>
<th>$h_A$</th>
<th>$h_C$</th>
<th>$h_A - h_C$</th>
<th>$h_B$</th>
<th>$h_D$</th>
<th>$i$</th>
<th>$M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>12.326</td>
<td>8.438</td>
<td>3.888</td>
<td>9.158</td>
<td>7.671</td>
<td>1.278</td>
<td>0.0144</td>
</tr>
<tr>
<td>0.6</td>
<td>12.555</td>
<td>8.502</td>
<td>4.053</td>
<td>9.164</td>
<td>7.591</td>
<td>1.265</td>
<td>0.0144</td>
</tr>
<tr>
<td>0.7</td>
<td>12.818</td>
<td>8.595</td>
<td>4.223</td>
<td>9.615</td>
<td>7.539</td>
<td>1.256</td>
<td>0.0145</td>
</tr>
<tr>
<td>0.8</td>
<td>13.165</td>
<td>8.739</td>
<td>4.426</td>
<td>9.946</td>
<td>7.533</td>
<td>1.255</td>
<td>0.0151</td>
</tr>
<tr>
<td>0.9</td>
<td>14.047</td>
<td>8.989</td>
<td>5.057</td>
<td>10.458</td>
<td>7.617</td>
<td>1.269</td>
<td>0.0163</td>
</tr>
<tr>
<td>0.95</td>
<td>14.786</td>
<td>9.726</td>
<td>5.059</td>
<td>10.903</td>
<td>7.753</td>
<td>1.352</td>
<td>0.0176</td>
</tr>
</tbody>
</table>

**Barren Cost**

\[ V_{1B} \times \text{unit cost} = \frac{3490 \text{yd}^3}{100 \text{yd}^3} \times 1.23 \]

\[ = \$4540 \text{ per 100 ft levee station} \]

**Riverside Blanket Cost**

\[ V_{2B} \times \text{unit cost} = \frac{2600 \text{yd}^3}{100 \text{yd}^3} \times 1.23 \]

\[ = \$32400 \text{ per 100 ft levee station} \]

**Cutoff Cost, $d_c/o = 0.95$**

\[ d_c + 2l = 0.95 \times (100) + 0 = 101 \text{ ft} \]

Area \( \times 3.00 \text{ ft}^2 = 65 \times 100 = 6500 \text{ ft}^2 \)

\[ \text{cost} = 6500 \times 3.00 = 19,500 \]

Area \( \times 8.00 \text{ ft}^2 = (101 - 65) \times 100 = 3600 \text{ ft}^2 \)

\[ \text{cost} = 3600 \times 8.00 = 28,800 \]

**Cutoff total cost \[ = \$48,300 \text{ per 100 ft levee station} \]**


Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 2 by \( \mu \)

Imperious Riverside and land side for stratum

[Diagram of levee cross-section with dimensions]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H )</td>
<td>25 ft</td>
</tr>
<tr>
<td>( L_1 \times x_1 )</td>
<td>7.00 ft</td>
</tr>
<tr>
<td>( L_2 \times x_2 )</td>
<td>5.00 ft</td>
</tr>
<tr>
<td>( D )</td>
<td>100 ft</td>
</tr>
</tbody>
</table>

Relief well analysis

Note: References to Figs. 60 and 61 are from USAE WES TH 3.424.

Lettered steps follow those given in TH 3.424 beginning on p. 295.

a) \( h_a = \frac{e}{x} \times 0.53 = 0.53(4) = 3.18 \text{ ft} \)

b) \( \Delta M = H - H_w \) \( \frac{H_w}{k_s} = 0.0154 \frac{25 - 3.18}{1000} = 0.0018 \text{ in/ft} \)

c) For \( P = 0.25 \), assume \( a = 75 \text{ ft} \)

\[ Q_w = a \Delta M \frac{k_f D}{25 (0.01546)(0.1)(14.72)(100)} = 170.0 \text{ gpm} \]

da) From Fig. 61, \( H_w = 0.55 \text{ ft} \)

e) \( h_w = H - H_w = 3.18 - 0.55 = 2.63 \text{ ft} \)

f) \( \Theta_w = \frac{h_w}{a \Delta M} \frac{2.63}{a (0.01546)} \frac{170.0}{a} \)

g) \( r_w = 141; D = 100 \text{ ft} \)

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \frac{q}{e} )</th>
<th>( D/a )</th>
<th>( \Theta_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>75</td>
<td>1.33</td>
<td>1.44</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>1.00</td>
<td>1.18</td>
</tr>
<tr>
<td>125</td>
<td>125</td>
<td>0.80</td>
<td>1.17</td>
</tr>
</tbody>
</table>

From Fig. 60,
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 2 by R.W.C.

Date 8/24/56 Page 5 of 19

<table>
<thead>
<tr>
<th>Relief well analysis (cont.)</th>
<th>( \rho ) of ( \Omega ) (cont.)</th>
</tr>
</thead>
</table>

h) 1st trial well spacing: \( \text{By inspection} \ \Omega_{av} = 1.84 \)

\[ d = 75 + 25 (42/52) = 95 ft \] (By interpolation of \( d \)'s and \( \Omega_{av} \)'s from step f). \[ \Omega_{av} = 1.77 \]

i) \( \Omega = 1.84 \Rightarrow \Omega_{av} = 1.77 \Rightarrow \text{Repeat steps e) to l) using } c = 90 \]

j) \( Q_w = 14.72 \text{ c.f.m.} \ \delta = 14.72 (90) (0.01546) (0.1) (10) = 205.9 \text{ gpm} \)

k) \( h_{av} = H_{av} - H_w = 3.12 - 0.40 = 2.52 \)

\[ \Omega_{av} = \frac{h_{av}}{a \ \delta} = \frac{2.52}{a (0.01546)} = 165.9 \]

l) \( \frac{\delta}{\delta'} = \frac{\delta}{\delta'} \)

<table>
<thead>
<tr>
<th>( \delta ) from Fig. 60</th>
<th>( \Omega_{av} )</th>
<th>( a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>2.23</td>
<td>75</td>
</tr>
<tr>
<td>90</td>
<td>1.84</td>
<td>90</td>
</tr>
<tr>
<td>100</td>
<td>1.67</td>
<td>100</td>
</tr>
</tbody>
</table>

m) \( \text{By inspection} \ \Omega_{av} = 1.84 \) and 2nd trial well spacing \( c = 90 \) ft

n) \( \text{from Fig. 60, } \Omega_{av} \text{ for } \frac{\delta}{\delta'} = 90 \) and \( \rho = 1.11 \) \( \Omega_{av} = 1.78 \)

\[ \Omega = 1.84 \Rightarrow \Omega_{av} = 1.78 \Rightarrow \text{Repeat steps e) to l) using } c = 90 \]

o) \( Q_w = 14.72 \text{ c.f.m.} \ \delta = 14.72 (90) (0.01546) (0.1) (10) = 205.9 \text{ gpm} \)

p) \( h_{av} = H_{av} - H_w = 3.12 - 0.40 = 2.52 \)

q) \( \Omega_{av} = \frac{h_{av}}{a \ \delta} = \frac{2.52}{a (0.01546)} = 165.9 \)

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \delta )</th>
<th>( \delta' )</th>
<th>( \Omega_{av} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>75</td>
<td>1.84</td>
<td>1.84</td>
</tr>
<tr>
<td>90</td>
<td>90</td>
<td>1.11</td>
<td>1.24</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Relief well analysis (con't)  P = 0.25 (cont'd)

h3) By inspection, \( \Theta_{aw} = 1.64 \)

By interpolation, relief well spacing \( a = 90 + 10 \left( \frac{1}{16} \right) = 91 \text{ ft} \)

Compare 91 ft with assumed 90 ft - close enough

Use \( \bar{a} = 91 \text{ ft} = a_{sel} \)

\[ Q_{aw} = 14.72 (91) (0.0154) (0.1)(100) \]

\[ \bar{w} = \frac{254}{25} \text{ gpm} \]

Cost per well:

\[ CW = (DR_t + RP) \bar{w} + (DR_p + WS + FL) \bar{w} + BF + WC + WD \]

For plastic pipe and screen

\[ = (20 + 30)(6) + (16 + 85 + 12)(25) + 400 + 500 + 1000 \]

\[ = \$ 4825 \]

Cost per 100 ft levee section:

\[ CW_S = CW (100/a_{sel}) = \frac{4825}{91} = \$ 530.2 \]

\[ P \leq 0.375 \]

c) Assume \( a = 125 \text{ ft} \)

\[ Q_{aw} = 14.72 a \text{ gpm} \text{ ft} D = 14.72 (125)(0.0154) (0.1)(100) \]

\[ = 254 \text{ gpm} \]

d) From fig. 61, \( H_w = 0.71 \)

e) \( h_{aw} = H_w - H_s = 2.18 - 0.71 = 1.47 \)

\[ \Theta_{aw} = \frac{h_{aw}}{a \Delta M} = \frac{1.47}{a(0.0154)} = \frac{159.8}{a} \]

\[ a \quad \Theta_{aw} \]

| \[ 100 \] | 1.40 |
| \[ 125 \] | 1.28 |
| \[ 150 \] | 1.07 |

g) \( h_w = 1.25; D = 100 \text{ ft} \)

| \[ a/\text{aw} \] | \[ P/k \] | \[ \Theta_{aw} \] |

| \[ 100 \] | 100 | 1.00 | 1.22 |
| \[ 125 \] | 125 | 0.80 | 1.24 |
| \[ 150 \] | 150 | 0.67 | 1.25 |

h) By inspection, \( \Theta_{aw} = 1.24 \)

By interpolation, \( a = 125 + 25 (4/21) = 130 \text{ ft} \)

E36
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 2 by Rue

Date: 6/4/56
Page: 10 of 19

Relief well analysis (cm.t) \( P = 0.375 \text{(cm.t)} \)

i) from fig. 61, \( \Theta w = 0.73 \) ft

m) \( h_m = H_m - H_w = 3.18 - 0.73 = 2.45 \) ft

n) \( h_m = 2.45 (1.24 / 1.31) = 2.32 \)

o) \( H_m = h_m + H_w = 2.32 + 0.73 = 3.05 \) ft

p) \( \Delta M = \frac{H - H_m - H_w}{S'} = \frac{25 - 3.05}{0.01585} = 0.01585 \)

q) \( \Theta_m = \frac{h_m}{\Delta M} = \frac{2.45}{0.01585} = 154.6 \)

r) from fig. 60, \( \Theta_m \) for \( \alpha / h_m = 1.25 \)

<table>
<thead>
<tr>
<th>( \alpha / h_m )</th>
<th>( \Delta M )</th>
<th>( \Theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
<td>1.00</td>
</tr>
<tr>
<td>125</td>
<td>125</td>
<td>1.27</td>
</tr>
<tr>
<td>150</td>
<td>150</td>
<td>1.03</td>
</tr>
</tbody>
</table>

s) By inspection \( \Theta_m = 1.29 \)

By interpolation, second trial well spacing \( \alpha = 100 + \left( \frac{25}{25} \right) 25 = 123 \) ft

\( \Theta_w = 1.23 \)

\( \Theta_m = 1.29 \)

E37
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 2 by RWC

Date 8/24/86

Page 11 of 19

Relief well analysis (cm'd) \( P = 0.375 \text{(cm'd)} \)

\[ R_2 \]

\[ H_m = 3.18 \quad Q_w = 14.72 \text{ cff} \text{ kbf} \]
\[ = 14.72 \times (123)(0.01552)(0.1)(10) = 280 \text{ gpm} \]

\[ R_2 \text{ from } Q_w \]

\[ H_w = 0.70 \text{ ft} \]

\[ h_m = H_w - H_w = 3.18 - 0.70 = 2.48 \text{ ft} \]

\[ R_1 \]

\[ h_{aw} = h_m (\Theta_m/\Theta_m) = 2.48 \times (1.28/1.29) = 2.36 \]

\[ R_2 \]

\[ H_m = h_{aw} + H_w = 2.36 + 0.70 = 3.06 \text{ ft} \]

\[ R_2 \]

\[ \Delta M = H_m - H_{aw} = \frac{28 - 3.06}{1000} = \frac{2.5}{500} = 0.01582 \]

\[ R_2 \]

\[ \Theta_m = \frac{h_m}{a \Delta M} = \frac{2.48}{a(0.01582)} = \frac{150.8}{a} \]

\[ a \quad \Theta_m \]

\begin{array}{c|c|c|c}
115 & 115 & 0.87 & 1.27 \\
125 & 125 & 0.80 & 1.30 \\
135 & 135 & 0.74 & 1.32 \\
\end{array}

\[ R_2 \]

By inspection \( \Theta_m = 1.29 \)

By interpolation rule well spacing \( a = 122 \text{ ft} \)

Compare 122 ft with assumed 123 ft - close enough

Use \( a = 122 \text{ ft} \)

\[ Q_w = 14.72 \times (122)(0.01552)(0.1)(100) = 254 \text{ gpm} \]

\[ H_w = 3.06 \text{ ft} \]

Cost per well (using plastic pipe)

\[ C_w = (DRT + RP)(39) + (DRP + W + FL)(30) + BF + WC + WD \]

\[ = (20 + 30)(6) + (16 + 65 + 12)(37.5) + 400 + 300 + 1000 \]

\[ = 6237 \]

Cost per 100 ft levee station

\[ CWS = C_W \times \frac{100}{a \text{ ft}} = \frac{6237}{122} \times \frac{100}{122} = \frac{5113 \text{ per } 100 \text{ ft}}{122} \]

E38
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 2 by RWC

Date 6/24/66
Page 12 of 19

Relief well analysis (cont.)

\( P = 0.50 \)

Case 1) Assume \( w = 150 \) ft

\[ Q_w = 14.72 \cdot \alpha \cdot \Delta M \cdot \beta \]

\[ = 14.72 \cdot 150 \cdot 0.01544 \cdot 0.15 = 3.419 \text{ gpm} \]

d) From fig. 61, \( H_w = 0.61 \)

e) \( h_{aw} = H_{aw} - H_w = 3.18 - 0.61 = 2.37 \) ft

f) \( \theta_{aw} = \frac{h_{aw}}{\alpha \cdot \Delta M} = \frac{2.37}{150 \cdot 0.01544} = \frac{153.3}{\alpha} \)

<table>
<thead>
<tr>
<th>( \alpha )</th>
<th>( \theta_{aw} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>1.27</td>
</tr>
<tr>
<td>150</td>
<td>1.02</td>
</tr>
<tr>
<td>175</td>
<td>0.88</td>
</tr>
</tbody>
</table>

From fig. 60, \( \theta_m \) for \( \alpha \cdot \Delta M = 147, \theta_m = 0.57 \)

\( \theta_m = 1.05 \)

h) By inspection \( \theta_{aw} = 1.05 \)

By interpolation 1st trial well spacing \( \alpha = 125 + 25 \cdot \left( \frac{1.05 - 1.03}{1.05 - 1.03} \right) = 147 \) ft

\( \theta_{aw} \) = 1.05 < \( \theta_m \) = 1.06

\( \theta_{aw} \) = 1.05 < \( \theta_m \) = 1.06

i) From fig. 60, \( \theta_m \) for \( \alpha \cdot \Delta M = 147, \theta_m = 0.57 \)

\( \theta_m = 1.05 \)

j) \( \theta_{aw} = 1.05 < \theta_m = 1.06 \) : Proceed with step (h) for \( \Delta M \)

k) Assume \( H_{aw} = h_{aw} = 2.37 \) ft

\[ Q_w = 14.72 \cdot \alpha \cdot \Delta M \cdot \beta \]

\[ = 14.72 \cdot 147 \cdot 0.01544 \cdot 0.15 = 33.59 \text{ gpm} \]

l) From fig. 61, \( H_w = 0.80 \) ft

m) \( h_w = H_{aw} - H_w = 2.37 - 0.80 = 2.38 \) ft

n) \( h_{aw} = h_w \cdot \left( \frac{\theta_{aw}}{\theta_m} \right) = 2.38 \cdot \left( \frac{1.05}{1.06} \right) = 2.36 \) ft

o) \( h_{aw} = h_{aw} + H_w = 2.36 + 0.80 = 3.16 \) ft

E39
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 2 by RWC

Date 6/24/65
Page 13 of 19

Relief well analysis (cm^3/t)  P = 0.50 (cm^3/t)

\[ p) \Delta M = \frac{H - Hw}{3} - \frac{Hw}{x_3} = \frac{25 - 3.18 - 2.38}{1000} = 0.01552 \]

\[ q) \Theta_m = \frac{m}{\alpha \Delta M} = \frac{2.38}{\alpha (0.01552)} = 153.4 \]

\[ P = 0.50 \]

\[ \Theta_m \]

<table>
<thead>
<tr>
<th>( \alpha )</th>
<th>( \Theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>1.10</td>
</tr>
<tr>
<td>150</td>
<td>1.02</td>
</tr>
<tr>
<td>160</td>
<td>0.96</td>
</tr>
</tbody>
</table>

r) From Fig. 40, \( \frac{Q}{m} = 145 \),

<table>
<thead>
<tr>
<th>( \frac{Q}{m} )</th>
<th>( \Delta M )</th>
<th>( \Theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>140</td>
<td>0.71</td>
</tr>
<tr>
<td>150</td>
<td>150</td>
<td>0.67</td>
</tr>
<tr>
<td>160</td>
<td>160</td>
<td>0.62</td>
</tr>
</tbody>
</table>

s) By inspection \( \Theta_m = 1.04 \)

By interpolation, \( \Theta_m = 0.94 \) and \( \Theta_m = 1.04 \)

x) From Fig. 61, \( \Theta_w = 0.96 \)

\[ D/a = 0.69 \]

\[ \Theta_w = 0.96 \]

w) Repeat steps r) to w) using \( \alpha = 145 \) ft

\[ \Theta_w = 0.96 \]

\[ \Theta_m = 1.04 \]

\[ \Theta_w = 0.96 \]

k) Assume \( Hw = 3.18 \) ft

\[ Q_w = 14.72 \alpha \Delta M \frac{P}{4} \]

\[ = 14.72 (145) (0.01546) (0.1) (100) \]

\[ = 330 \text{ gpm} \]

l) from Fig. 61, \( Hw = 0.79 \)

m) \( Hw = Hw - Hw = 3.18 - 0.79 = 2.39 \)

n) \( Hw = Hw (\Theta_w / \Theta_m) = 2.39 (0.96/1.04) = 2.16 \)

o) \( Hw = Hw + Hw = 2.16 + 0.79 = 2.95 \)

p) \[ \Delta M = \frac{H - Hw}{5} - \frac{Hw}{x_3} = \frac{25 - 2.95 - 2.95}{1000} = 0.01535 \]

E40
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 3 by RWG

Date 8/24/66
Page 14 of 19

Relief well analysis (cm³/hr) \[ P = 0.50 \text{ (cm³/hr)} \]

\[ q_{21} \quad \Theta_m = \frac{h_m}{a \Delta M} = \frac{2.35}{a (0.01615)} = \frac{148.3}{a} \]

<table>
<thead>
<tr>
<th>[ a ]</th>
<th>[ \Theta_m ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>1.04</td>
</tr>
<tr>
<td>145</td>
<td>1.02</td>
</tr>
<tr>
<td>150</td>
<td>0.99</td>
</tr>
</tbody>
</table>

2) From fig. 60, \[ \frac{a}{\Delta h} \]

<table>
<thead>
<tr>
<th>[ a ]</th>
<th>[ \frac{a}{\Delta h} ]</th>
<th>[ \frac{D/a}{\Theta_m} ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>140</td>
<td>0.71</td>
</tr>
<tr>
<td>145</td>
<td>145</td>
<td>0.69</td>
</tr>
<tr>
<td>150</td>
<td>150</td>
<td>0.67</td>
</tr>
</tbody>
</table>

31) By inspection \[ \Theta_m = 1.05 \]

32) By interpolation the 3rd trial well spacing

\[ a = 140 + 5 (\frac{1}{4}) = 141 \text{ ft} \]

4) From fig. 60, \[ \Theta_w \] for \[ \frac{a}{\Delta h} = 141 \]

\[ 141 \text{ ft} \]

\[ \Theta_w = 0.96 \]

M2) Repeat steps k) to m) using \[ a = 141 \text{ ft} \]

\[ \Theta_w = 0.96 \]

\[ \Theta_m = 1.05 \]

k2) \[ H_m = 3.18 \text{ ft} \]

\[ Q_w = 14.72 (a) (a M) (\frac{h_m}{a}) (D) \]

\[ = 14.72 (141) (0.01546) (0.1) (100) \]

\[ = 321.9 \text{ gpm} \]

l3) From fig. 61, \[ H_w = 0.77 \text{ ft} \]

m3) \[ H_m = H_m - H_w = 3.18 - 0.77 = 2.41 \text{ ft} \]

n3) \[ h_{aw} = h_m (\Theta_w/\Theta_m) = 2.41 (0.96/1.05) = 2.20 \text{ ft} \]

o3) \[ H_w = h_{aw} + H_w = 2.20 + 0.77 = 2.97 \text{ ft} \]

p3) \[ \Delta M = \frac{H - H_{aw} - H_{aw}}{\frac{h_{aw}}{\lambda}} \]

\[ \frac{25 - 2.97}{2.97} = \frac{22.03}{500} \]

\[ = 0.04409 \]
Levee Underseepage Computation Program

Hand Computations used for Verification
Cross Section No. 2 by RWK

Date 8/24/86
Page 15 of 19

Relief well analysis (cm³/ft)

P = 0.50 (cm³/d)

\[ \Theta_m = \frac{h_n}{a \Delta M} = \frac{2.41}{a(0.01609)} = 141.8 \]

\[ \Theta_m \]

<table>
<thead>
<tr>
<th>a</th>
<th>[ \Theta_m ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>1.05</td>
</tr>
<tr>
<td>145</td>
<td>1.05</td>
</tr>
<tr>
<td>150</td>
<td>0.99</td>
</tr>
</tbody>
</table>

\[ a \Delta M \]

<table>
<thead>
<tr>
<th>a</th>
<th>[ a \Delta M ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>145</td>
<td>145</td>
</tr>
<tr>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

\[ \frac{a}{a \Delta M} \]

By inspection \( \Theta_m = 1.05 \)

By interpolation well spacing \( a \Delta M = 142 \text{ ft} \)

Since 142 compares favorably with 141

\[ Q_{w} = \frac{14.72 (142)(10.01009)(0.1)(100)}{2} \]

\[ = 336.8 \text{ gpm} \]

\[ \bar{W} = 50 \text{ ft} \]

\[ C_W = (D_R + R_P) \bar{W} + (D_R + W_S + F_L) \bar{W} + B_F + W_C + W_D \]

\[ = (20 + 30) 6 + (16 + 95 + 12) 50 + 40 + 300 = 7650 \text{ per well using plastic pipe} \]

Cost per 100 ft of levee station

\[ C_{WS} = C_W \left( \frac{100}{a \Delta M} \right) = \frac{7650 (100/142)}{5.387 \text{ per 100 ft}} \]

E42
Levee Underseepage Computer Program
Hand Computations used for Verification
Cross Section No. 2 by RWC

Date 3/24/66
Page 16 of 14

Relief well analysis (cm^4) \( P = 0.75 \)

c) Assume \( a = 175 \) ft
\( Q_w = 14.72 a DM y D \)
\[ = 14.72(175)(0.01546)(0.1)(100) = 598 \text{ gpm} \]
d) From Fig. 61, \( H_w = 0.92 \)
e) \( h_w = H_w - H_a = 3.18 - 0.92 = 2.26 \) ft
f) \( \Theta_{av} = \frac{h_w}{a DM} = \frac{2.26}{a(0.01546)} = \frac{144.2}{a} \)

\begin{tabular}{|c|c|c|c|c|}
\hline
\( a \) & \( h_w \) & \( \Theta_{av} \) \\
\hline
150 & 150 & 0.61 & 0.65 \\
175 & 175 & 0.57 & 0.68 \\
200 & 200 & 0.50 & 0.71 \\
225 & 225 & 0.44 & 0.72 \\
\hline
\end{tabular}

h) By inspection \( \Theta_{av} = 0.71 \)

By interpolation \( a \) for 1st trial well spacing \( = 200 + 0.71(175 - 150) = 206.4 \) ft

i) From Fig. 60, \( Q_m \) for \( \theta_{av} = 206, \quad \theta_{av} = 0.49 \)
\( Q_m = 0.82 \)

j) \( \quad 0.71 < \theta_{av} = 0.82 : \text{ Proceed with steps k) to m) } \)
k) Assume \( H_m = h_w = 3.18 \) ft; \( Q_m = 14.72(206)(0.01546)(0.1)(100) = 467 \) gpm

l) From Fig. 61, \( H_w = 1.05 \) ft

m) \( h_m = H_m - H_w = 3.18 - 1.05 = 2.13 \) ft

n) \( h_w = h_m (\Theta_{av}/\Theta_m) = 2.13 (0.71/0.82) = 1.84 \)
o) \( h_{av} = h_w + h_m = 1.84 + 1.05 = 2.89 \) ft

p) \( \Delta M = \frac{H - h_{av}}{S} = \frac{25 - 2.89}{100.0} = \frac{2.51}{500} = 0.01433 \)

E43
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 2 by RUO

Date 8/24/16
Page 17 of 19

Relief well analysis (cm³)

P = 0.75 (cm³)

q) \( q_m = \frac{h_m}{a \Delta M} = \frac{3.13}{a(0.01433)} = 130.4 \)

\( \begin{array}{c|c|c|c}
 a & q_m & \Delta M & \Theta_m \\
 \hline
 150 & 150 & 0.67 & 0.78 \\
 175 & 175 & 0.57 & 0.80 \\
 200 & 200 & 0.50 & 0.81 \\
\end{array} \)

\( \Theta_m = 0.79 \)

By interpolation: 2nd trial were spacing \( a = 150 + 25(6/12) = 167 \text{ ft} \)

\( \Theta_m = 0.79 \)

\( \Theta_m = 0.67 \)

\( \Theta_m = 0.79 \)

Assume \( h_m = 3.13 \text{ ft} \)

\( Q_u = 14.72 a \Delta h \frac{k_f D}{D} \)

\( = 14.72(167)(0.01546)(0.1)(100) = 3600 \text{ gpm} \)

b) \( H_u = 0.90 \text{ ft} \)

c) \( h_m = H_m - H_u = 3.18 - 0.90 = 2.28 \text{ ft} \)

d) \( h_w = h_m (\Theta_w/\Theta_m) = 2.28(0.67/0.79) = 1.93 \text{ ft} \)

e) \( H_w = h_w + H_u = 1.93 + 0.90 = 2.83 \text{ ft} \)

f) \( \Delta M = \frac{H - H_w}{5} - \frac{H_w}{X_3} \)
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 2 by RWC

Date 5/24/86
Page 18 of 19

Relief well analysis (con't)

2) \[ \theta_m = \frac{ha}{aD_M} = \frac{228}{a(0.01651)} = 138.1 \]

\[ \begin{array}{c|c|c|c|c}
\hline
\theta_m & 160 & 140 & 0.92 & 0.79 \\
\hline
a & 170 & 170 & 0.59 & 0.80 \\
\hline
D_M & 180 & 180 & 0.59 & 0.80 \\
\hline
\end{array} \]

3) By inspection \( \theta_m = 0.80 \)

By interpolation 3rd trial well spacing

\[ a = 170 + 10 \left( \frac{3}{4} \right) = 172 ft \]

4) from fig. 60, \( \theta_w \) for \( \sqrt{a} = 172, \ D_M = 0.58 \)

\[ \theta_w = 0.67 \]

5) Repeat steps 2) to 4) using \( a = 172 ft \)

\[ \theta_w = 0.67 \]

\[ \theta_m = 0.80 \]

6) Assume \( h_m = 3.18 ft \)

\[ Q_w = 14.72 aD_M \frac{h_m}{D} \]

\[ = 14.72 (172) (0.01546) (0.1)(100) = 39.1 qpm \]

7) from fig. 61, \( h_w = 0.91 ft \)

8) \( h_m = h_m - h_w = 2.28 - 0.91 = 2.27 ft \)

9) \( h_w = h_m (\theta_m/\theta_w) = 2.27 (0.80/0.67) = 1.90 ft \)

10) \( h_w = h_w + h_w = 1.90 + 0.91 = 2.81 ft \)

\[ \Delta M = \frac{h_w - h_w}{s} \]

\[ = \frac{25 - 2.81}{100} = 0.01657 \]
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 2 by RWC

\[ P = 0.75 \text{ (con'd)} \]

9.1) \( \Theta_m = \frac{\ln m}{a \Delta n} = \frac{2.27}{a (0.01657)} = \frac{137.0}{a} \)

\( a \) \( \Theta_m \) 
---
160 0.84
170 0.81
180 0.76

9.2) From fig. 60. \( a \) \( a/\ln a \Delta n \) \( D/\alpha \) \( \Theta_m \)

---
160 160 0.62 0.79
170 170 0.59 0.60
180 180 0.56 0.60

9.3) By inspection: \( \Theta_m = 0.80 \)

By interpolation, well spacing \( a = 170 + 10 (0.8) \)

\( = 172 \text{ ft} \)

172 ft is the same as the 3rd trial well spacing

\( a_{sel} = 172 \text{ ft} \)

\( Q_w = 14.72 (172)(0.01657)(0.1)(100) \)

\( = 391.9 \text{ gpm} \)

\( \bar{w} = 75 \text{ ft} \)

Cost per well (plastic pipe)

\( C_w = (DRT + RP)(a_{sel}) + (DRP + WS + FL)\bar{w} + BF + WC + WD\)

\( = (20 + 30)6 + (16 + 85 + 12)(75) + 400 + 300 + 1000 \)

\( = $10475 \)

Cost per 100 ft of levee station

\( C_{ws} = C_w \left( \frac{100}{a_{sel}} \right) = \frac{$10475 \cdot 100}{172} = \frac{$6090}{100 \text{ ft}} \)
PROJECT NAME : PROGRAM DEVELOPMENT
STATION : X-SECT. 2

GENERAL CONTROL MEASURE INPUT DATA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>LTE</td>
<td>165 FT</td>
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<tr>
<td>BL</td>
<td>25 FT</td>
</tr>
<tr>
<td>LTE0</td>
<td>120 FT</td>
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<tr>
<td>RTO</td>
<td>100 FT</td>
</tr>
<tr>
<td>L1</td>
<td>780 FT</td>
</tr>
<tr>
<td>L3</td>
<td>500 FT</td>
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<tr>
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<td>OPEN</td>
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<td>OPEN</td>
</tr>
<tr>
<td>D</td>
<td>100 FT</td>
</tr>
<tr>
<td>DD</td>
<td>100 FT</td>
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<tr>
<td>ZBL</td>
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<tr>
<td>KBL</td>
<td>0 CM/S</td>
</tr>
<tr>
<td>ZBR</td>
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<tr>
<td>KBR</td>
<td>0 CM/S</td>
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<tr>
<td>ZT</td>
<td>6 FT</td>
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<tr>
<td>KF</td>
<td>0.1 CM/S</td>
</tr>
<tr>
<td>ZL</td>
<td>6 FT</td>
</tr>
<tr>
<td>SUBWT</td>
<td>50. LB/CU FT</td>
</tr>
</tbody>
</table>

SUPPLEMENTAL CONTROL MEASURE INPUT DATA

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<tr>
<td>I0B</td>
<td>0.3</td>
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<tr>
<td>I1</td>
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<tr>
<td>M1</td>
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<tr>
<td>M3B</td>
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<tr>
<td>IA</td>
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<td>M3R</td>
<td>0.25</td>
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<tr>
<td>M4</td>
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<td>RELIEF WELL</td>
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<tr>
<td>FSW</td>
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<tr>
<td>IOW</td>
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<tr>
<td>RW</td>
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<tr>
<td>DP</td>
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<tr>
<td>RUFF</td>
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<tr>
<td>VISCONS</td>
<td>0.0000121 GAL*FT/SEC</td>
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<tr>
<td>J</td>
<td>UNDEFINED %</td>
</tr>
<tr>
<td>HEL</td>
<td>0.33 FT</td>
</tr>
</tbody>
</table>
PROJECT NAME: PROGRAM DEVELOPMENT
STATION: X-SECT. 2

LEVEE UNDERSEEPAGE ANALYSIS
INITIAL CONDITIONS

\begin{align*}
X_1 &= 780. \text{ FT} \\
X_3 &= 500. \text{ FT} \\
M &= 0.1667 \times 10^{-1} \\
I &= 1.389 \\
Q_S &= 246. \text{ GPM/100 FT} \\
H_0 &= 8.3 \text{ FT} \\
\$ &= 0.6667 \times 10^{-1}
\end{align*}
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 2

OUTPUT DATA FOR BERM ANALYSIS
------------------------

\[ X_1 = 780. \text{ FT} \]
\[ X_3 = 500. \text{ FT} \]
\[ M = 0.1667 \times 10^{-3} \]
\[ I = 0.167 \]
\[ Q_s = 246. \text{ GPM/100 FT} \]
\[ X = 212. \text{ FT} \]
\[ T = 6.3 \text{ FT} \]
\[ V_B = 3478. \text{ CU YD/100 FT LEVEE STATION} \]

BERM COST CALCULATION
----------------------

\[ V_B = 3478. \text{ CU YD/100 FT LEVEE STATION} \]
\[ \text{UNIT COST} = \$1.30 / \text{CU YD} \]
\[ \text{TOTAL COST} = \$4520.00 /100 \text{ FT LEVEE STATION} \]
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 2

OUTPUT DATA FOR BLANKET ANALYSIS

\[\begin{align*}
X_1 &= 1475. \text{ FT} \\
X_3 &= 500. \text{ FT} \\
M &= 0.8404 \times 10^{-2} \\
I &= 0.700 \\
Q_s &= 124. \text{ GPM/100 FT} \\
XR &= 1476. \text{ FT} \\
LB &= 1917. \text{ FT} \\
KB &= 0.1000 \times 10^{-4} \text{ CM/S} \\
ZB &= 3.0 \text{ FT} \\
VR &= 27298. \text{ CU YD/100 FT LEVEE STATION} \\
\text{IF XR OR LB > DISTANCE TO RIVER, SOLUTION INFEASIBLE}
\end{align*}\]

BLANKET COST CALCULATION

\[\begin{align*}
\text{VOLUME} &= 27298. \text{ CU YD/100 FT LEVEE STATION} \\
\text{UNIT COST} &= \$1.20 /\text{CU YD} \\
\text{COST} &= \$32757.00 /\text{100 FT OF LEVEE STATION}
\end{align*}\]
PROJECT: PROGRAM DEVELOPMENT  
STATION: X-SECT. 2

OUTPUT DATA FOR CUTOFF ANALYSIS

\[
\begin{align*}
DC/D &= 0.950 \\
X_1 &= 780. \text{ FT} \\
X_3 &= 500. \text{ FT} \\
M &= 0.1765E-01 \\
I &= 1.292 \\
Q_s &= 193. \text{ GPM/100 FT}
\end{align*}
\]

\[\text{Hand Calculations}\]

\[
\begin{align*}
X_1 &= \text{780.} \\
X_3 &= \text{500.} \\
M &= \text{0.0175} \\
I &= \text{1.29} \\
Q_s &= \text{193.}
\end{align*}
\]

CUTOFF COST CALCULATION

\[
\begin{align*}
\text{DEPTH} &= 101. \text{ FT} \\
\text{COST} &= \$48300.00 /100 \text{ FT OF LEVEE STATION}
\end{align*}
\]

\[\text{48,300}\]
OUTPUT DATA FOR RELIEF WELL ANALYSIS

Hand Calculations

<table>
<thead>
<tr>
<th>P</th>
<th>ASEL</th>
<th>WBAR</th>
<th>GW</th>
<th>COST</th>
</tr>
</thead>
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<td>25.</td>
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<tr>
<td>.375</td>
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<td>38.</td>
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<td>5200.00</td>
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<td>.500</td>
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<td>50.</td>
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<td>.625</td>
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<td>.750</td>
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<td>75.</td>
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<tr>
<td>.875</td>
<td>196.</td>
<td>88.</td>
<td>468.</td>
<td>6078.00</td>
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<tr>
<td>1.000</td>
<td>207.</td>
<td>100.</td>
<td>483.</td>
<td>6414.00</td>
</tr>
</tbody>
</table>
| .375  | 120. | 38.  | 273.  | 5200.00  <= MINIMUM COST
Cross Section 3
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 3 by RWC

Previous top stratum, infinite landslide: Initial Conditions

\[ \chi_3 = \frac{\text{tan} \theta \cdot c_{ba} \cdot L_3}{c_{ba}} \quad \text{when} \quad c_{ba} = \left( \frac{k_{o1}}{k_{o2} \cdot z_{bb} \cdot d} \right)^{1/2} \]

\[ = \left( \frac{0.5 \times 10^{-4}}{1000 \times 10^{-4} \cdot 6 \times 100} \right)^{1/2} \]

\[ = 7.8 \, \text{ft} \]

\[ \chi_1 = \frac{\text{tan} \theta \cdot (1.00913)(980)}{0.00913} \]

\[ = 44.7 \, \text{ft} \]

\[ \chi_2 = \frac{1}{0.00236} \]

\[ = 447 \, \text{ft} \]

\[ h_o = \frac{447 \times 7.1}{780 + 220 + 447} \]

\[ = 7.7 \, \text{ft} \]

\[ i = \frac{h_o}{3x} \]

\[ = \frac{7.7}{6} \]

\[ = 1.28 \]

E56
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 3 by RWC

Initial condition calculations (cm/sec)

\[
M = \frac{H}{x_1 + x_2 + x_3} = \frac{25}{750 + 220 + 447} = 0.0173
\]

\[
Q_3 = \frac{1472 \times 1000 \times 10^{-4} \times 25 \times 100}{750 + 220 + 447} = 254.9 \text{ cm}^3/\text{sec of levee station}
\]

Beam analysis since \(i > 0.8\), design beam for \(i_0 = 0.3\)

Impervious beam

\[
\bar{x}_3 = x_3 \left( \frac{h}{h_0} - 1 \right) - 5 \quad \text{where} \quad h_0 = 2, x_0 = 0.8, h = 4.8 \text{ ft}
\]

and \(s = x_1 + x_2 = 750 + 220 = 1000 \text{ ft}\)

\[
= 447 \left( \frac{25}{4.8} - 1 \right) - 1000
\]

\[
= 882 \text{ ft but } 150 \leq \bar{x} < 400; \therefore \bar{x} = 400 \text{ ft}
\]

since \(\bar{x}\) is cut back from 882 ft to 400 ft calculate new \(h_0\) assuming \(i = 0.8\) at toe of beam.

\[
h_0' = 0.8 x_0 + \left( H - 0.8 x_0 \right) \left( \frac{\bar{x}_{\text{max}}}{s + \bar{x}_{\text{max}}} \right)
\]

\[
= 0.8(6) + (25 - 0.8(6)) \left( \frac{400}{1000 + 400} \right)
\]

\[
= 10.16 \text{ ft}
\]

\[
\text{trial } k = 1.25 \left( \frac{h_0' - 2x_0 x_0}{1 + x_0} \right)
\]

\[
= 1.25 \left( \frac{10.16 - 0.3(6)}{1 + 0.3} \right) = 8.4 \text{ ft}
\]
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 3 by Ruc

Date 5/5/67
Page 3 of 20

Imperious berms analysis (c nud)

test for berm slope:

\[ m_L = \frac{1 - 2}{2 - 2} = \frac{0.1}{0.25} = 0.4 < m_{min} = 0.02 \]

\[ \therefore \text{it must be increased} \]

\[ t = m_{min} (2/2 - 2/2) + 2 = 0.02 (400 - 2/2) + 2 = 9.8 \text{ft} \]

\[ \text{test for } h_b = \frac{m_c t}{m_{min}} = 0.25 (9.8) \]

\[ = 10.7 \frac{ft}{H} \approx 25 \text{ ft} = 30 \text{ ft} \]

\[ V_R = \left[ \frac{2x^2}{2} + \frac{2}{2} (2 - 2/2) + \frac{x}{2} (2 - 2/2) \right] \frac{100}{27} \]

\[ = \left[ \frac{2x^2}{2} + (9.8+2) (400 - 2/2) + \frac{9.8}{2} (0.25 - 0.02) \right] \frac{100}{27} \]

\[ = 9370 \text{ yd}^3 / 100 \text{ ft levee station} \]

Cost for Imperious berm:

\[ \text{Cost} = V_R \times \text{unit cost} \]

\[ = 9370 (0.30) \approx 12,200 /100 \text{ ft levee station} \]

with berm \( x_3, M_1, \lambda_b \) and \( Q_3 \) are undefined

Semi imperious berm analysis

\[ \bar{x}_{3p} = -A + \left[ A^2 - 24 (2 + \lambda)(1 + 5c_{kq} - \frac{M_1}{h_{a}}) \right] \frac{1}{2} \]

\[ \frac{2c_{kq}}{(2 + \lambda)} \]

where \( A = 6 + 3 \times c_{kq} (x + 1) \)

\[ s = \chi_1 - L_2 = 180 + 220 = 400 \]

\[ \alpha = \lambda_0 / \lambda_1 = 0.3 / 0.8 = 0.375 \]

\[ h_a = 2 + \lambda_2 = 0.8 (4) = 4.8 \]

E58
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 3 by RUW

Date 8/21/85
Page 4 of 20
Rev 5/5/87

Beam analysis (cm^4): Semipervious berm (cont)

\[ A = (a + 3(1000)(0.002234)(0.375 + 1)) = 15.22 \]

\[ \bar{x}_{sp} = \frac{-15.22 + \left[15.22^2 - 2 \frac{4(2 + 0.375)^2}{2 + (0.002234)(0.375)} \right]^{1/2}}{2(0.002234)(2 + 0.375)} \]

\[ = 3.14 \text{ ft} \]

\[ h'e = h_a \left[ 1 + \frac{c_{km} \bar{x}_{sp} + (2 + \frac{5}{2})(c_{km} \bar{x}_{sp})^2}{c_{km} \bar{x}_{sp}} \right] \]

\[ = 4.3 \left[ 1 + (0.002234)(3.14) + \frac{(2 + 0.375)}{2} \right] \left(0.002234 \bar{x}_{sp} \right)^2 \]

\[ = 9.11 \text{ ft} \]

Trial \( t = 1.25 \left( \frac{h'e - h_0 \bar{x}_{sp}}{1 + \frac{5}{2}} \right) = 1.25 \left( \frac{9.11 - 0.3 \times 3}{1 + 0.3} \right) = 7.03 \text{ ft} \]

check \( m_2 = \frac{t^2}{\bar{x}_{sp} - y} = \frac{7.03 - 2}{3.14 - 2} = 0.016 < 0.02 \text{ too small} \)

\( t \) must be increased \( = m \frac{\bar{x}_{sp} - y}{2} + 2 = 0.02(3.14 - 2) + 2 = 8.14 \text{ ft} \)

check \( h_a = m \frac{h_a}{m - m_2} = 0.02(1.1)(0.02 - 0.01) = 8.8 < 14 = 25 \text{ too small} \)

\[ V_B = \frac{8 + \left( \frac{h_a}{2} \right)(\bar{x}_{sp} - y) + \frac{t^2}{2(m - m_2)}}{2 \times 0.02} \]

\[ = \frac{8 + \left( \frac{4.3}{2} \right)(3.14 - 2) + \frac{7.03^2}{2(0.02 - 0.02)}}{27} \]

\[ = \frac{6280 \text{ yd}^3}{100 \text{ ft levee station}} \]

With beam \( x_3, M, l, i, Q \) undefined

Previous berm with collector

\[ \bar{x}_p = x_3 \frac{h'e}{h_a} \text{ where } h'e = \frac{H x_3}{x_1 + L x_3} = \frac{25 \times 4.47}{780 + 220 + 447} \]

\[ = 7.7 \text{ ft} \]

\[ h_a = x_{1.2} = 0.8 \times 6 = 4.8 \text{ ft} \]
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 3 by R.W.C.

Date 3/11/85
Page 5 of 26
Rev 5/15/87

Bern analysis: Previous berms with collector (cont'd)

\[
\bar{X}_p = 447 \ln \frac{7.7}{4.8} = \frac{211}{ft}
\]

Trial \( t = 1.25 \left( \frac{h_0 - \frac{1}{2} \bar{X}_p}{1 + t} \right) = 1.25 \left( \frac{7.7 - 0.3 \times 6}{1 + 0.3} \right)
\]

\[= 5.7 \text{ ft} \]

Check \( m_v = \frac{\bar{X}_p - 8}{\bar{X}_p - 8} = 2.11 / 2.11 = 0.02 < 0.02 \text{ it's too small} \]

\[t_{min} = \frac{5\bar{t} + 0.02 (\bar{X}_p - 2) m_t}{2} \text{ it's greater} \]

\[
\bar{t} = 0.02 (211 - 2.025) + 2 = 6.1 \text{ ft}
\]

Check \( h_v = m_t A_{m_t - m_v} = 0.25 (6.2) / (0.15 \times 0.01) = 68 < 110 \text{ it's too high} \)

\[
V_0 = \left[ \frac{h_v + \left( \frac{5.1 - 2}{2} \right)}{2(m_t - m_v)} \right] \text{ 100 ft levee station}
\]

Note: No cost estimate
is made for previous
berm since there is
no recent construction
experience.

Saw berm

\[
\bar{X}_s = \frac{1}{3} (\bar{X}_p + 2 \bar{X}_{sp}) = \frac{1}{3} [211 + 2(314)]
\]

\[= \frac{280}{ft} \]

\[
h_v' = h_v \left[ 1 + \frac{c_{be} \bar{X}_s + (\frac{2 + t}{L}) (c_{be} \bar{X}_s)^2}{2} \right]
\]

\[= 4.8 \left[ 1 + (0.02236)(280) + \left( \frac{2 + 0.25}{2} \right)(0.02236 \times 280)^2 \right]
\]

\[= 8.5 \text{ ft} \]

Trial \( t = 1.25 \left( \frac{h_v' - \frac{1}{2} \bar{X}_s}{1 + t} \right) = 1.25 \left( \frac{8.5 - 0.3 \times 6}{1 + 0.3} \right)
\]

\[= 6.4 \text{ ft} \]

Check \( m_v = \frac{\bar{X}_p - 8}{\bar{X}_p - 8} = \frac{2.11 - 7}{280 - 8} = 0.016 < 0.02 \text{ it's too small} \)

\[t \text{ must be increased} = m_v A_{m_v - m_p}. (\bar{X}_s - 8) + 2 = 0.02 (280 - 8) + 2 = 7.4 \text{ ft} \]
**Levee Underseepage Computer Program**

Hand Computations used for Verification  
Cross Section No. 3 by EWC  

Hand Computations used for Verification  
Cross Section No. 3 by EWC  

Date 8/22/85  
Page 12 of 20  
Rev 5/16/87

**Berm analysis: Sand berm (con'd)**

\[
V_{b} = \left[ \frac{2}{3} \left( \frac{1 + \sqrt{2}}{2} \right) \left( \bar{x}_s - \bar{r} \right) + \frac{\bar{z}}{2(\bar{m}_1 - \bar{m}_2)} \right] \frac{100}{\bar{L}}
\]

\[
= \left[ \frac{2}{3} \left( \frac{7.4 + 2}{2} \right) \left( \bar{x}_s - \bar{r} \right) + \frac{7.4}{2(0.15 - 0.03)} \right] \frac{100}{\bar{L}}
\]

\[
= 5.21 \times 10^3 \text{ ft}^3 \text{ per 100 ft levee station}
\]

With berm \( x_s, M, i, \bar{Q}_s \) are undefined

**Riverside blanket analysis (uniform thickness)**

Reduce \( h_a \) at landside levee toe by increasing the thickness of riverside top station (case II) No borrow pit, \( \bar{Q}_a = 0 \)

\[
\bar{x}_a = \frac{x_s \left( \frac{H}{h_a} - 1 \right)}{K_a} \quad \text{where} \ h_a = \frac{h_a \bar{Q}_s}{0.7 \times 6} = 4.2 \text{ ft}
\]

\[
= 447 \left( \frac{25}{4.2} - 1 \right) - 100
\]

\[
= 19.94 \text{ ft} 
\]

Input \( L_1 = 2500 \text{ ft} \)

\[
2_0 = 6.41
\]

By trial and error calculate \( C_{BB} \) from:

\[
x_a = \tan \theta \cdot C_{BB} \cdot L_1
\]

<table>
<thead>
<tr>
<th>Trial ( C_{BB} )</th>
<th>( x_a \cdot C_{BB} )</th>
<th>( C_{BB} \cdot L_1 )</th>
<th>( \tan \theta \cdot C_{BB} \cdot L_1 )</th>
<th>( x_a \cdot C_{BB} - \tan \theta \cdot C_{BB} \cdot L_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0004</td>
<td>0.7972</td>
<td>1.000</td>
<td>0.76159</td>
<td>0.03841</td>
</tr>
<tr>
<td>0.0008</td>
<td>0.71748</td>
<td>0.900</td>
<td>0.71630</td>
<td>0.00130</td>
</tr>
<tr>
<td>0.0005</td>
<td>0.69755</td>
<td>0.875</td>
<td>0.70368</td>
<td>-0.00632</td>
</tr>
</tbody>
</table>

Use \( C_{BB} = 0.000858 \)

\[
2_{EB} = 2_{e_a} + 2_{e_b} = 6 + 6 = 12
\]

\[
K_{EB} = \frac{e_{BB}^2 \bar{L}^2}{2 \bar{Q}_s}
\]

\[
= \frac{0.000858^2 \times 1000 \times 10^{-4}}{12 \times 100}
\]

\[
= 0.153 \times 10^{-4} \text{ cm/sec}
\]
Levee Underseepage Computer Program

Hand Computations used for Verification Date 8/22/85
Cross Section No. 3 by RUC Page 7 of 20
Ver. 5/15/87

Riverside blanket analysis (cont'd) [uniform thickness]

\[
\chi_b = \frac{Eb}{EB} = \frac{6}{12 - \frac{6}{0.5 \times 10^{-4}}} = 0.09 \times 10^{-4} \text{ cfm/sec}
\]

\[
V_{RB} = \frac{(2b \times L_1)}{L_1} = \frac{6 \times 2500 \times 100}{27} = \frac{55,600 \text{ yd}^3}{100 \text{ ft}}
\]

Cost of blanket = \[V_{RB} \times \text{unit cost} = \frac{55,600 \times 5.20}{1 \text{ ft}} = \frac{64,700}{100 \text{ ft}} \text{ of levee station} \]

with riverside blanket

\[
\chi_1 = \frac{\text{tank CBB L}_1}{CBB} = \frac{\text{tank (0.000 358) x 2500}}{0.000 358} = 1994 \text{ ft}
\]

\[
\chi_3 = \left(\frac{k_3 b_b d_0}{k_{be}}\right)^{1/2} = \left(\frac{1000 \times 10^{-8} \times 6 \times 100}{3 \times 10^{-4}}\right)^{1/2} = 447 \text{ ft}
\]

\[
M = \frac{H}{\chi_1 + \chi_2 + \chi_3} = \frac{25}{1994 + 220 + 447} = 0.00939
\]

\[
\chi = \frac{h_0}{x} \quad \text{where} \quad h_0 = \frac{H x_3}{\chi_1 + \chi_2 + \chi_3}
\]

\[
\dot{Q}_3 = 1472 \frac{b_3 H D}{\chi_1 + \chi_2 + \chi_3} = \frac{1472 \times 1000 \times 10^{-8} \times 25 \times 100}{1994 + 220 + 447} = 138 \text{ gpm / 100 ft levee station}
\]
Levee Underseepage Computer Program

Hand Computations Used for Verification
Cross Section No. 3 by Zuc.

Riverside Blanket - Triangular Section

Tacitly assume that \( \eta_B = 0 \)

\[
X_B = X_3 \left( \frac{h_B}{h_a} - 1 \right) - L_z \quad \text{where } h_a : L_a X_a = 0.7 \times 4.2 = 4.2 \text{ ft} \\
= 4.47 \left( \frac{25}{4.2} - 1 \right) - 220 = 1994 \text{ ft}
\]

\[
\frac{\eta_B}{h_B} = \frac{L_B \chi \eta}{(L_B - 1) \chi h_B D} \\
= \frac{2500(1994)}{1994 - 1}(0.1)(100)
\]

(1) \( \text{For } \eta_B = 0.09 \times 10^{-4} \text{ cm/sec} \), \( \eta_B = 17.7 \text{ ft} \)

(2) \( \text{For } h_B = 0.85 \times 10^{-4} \text{ cm/sec} \), \( \eta_B = 9.8 \text{ ft} \)

For \( \eta_B = 9.8 \text{ ft} = \) thickness at riverside toe

\[
V_{TRB} = \left( \frac{m_4 - m_5}{m_4 - m_5} \right) \frac{100}{27} \quad \text{where } m_5 = \frac{\eta_B - \eta_3}{H - X_B}
\]

\[
= \left[ (0.25) \frac{9.8}{(0.25 - 0.00315)} \right] \left( \frac{2500 + \frac{9.8}{0.15 - 0.00315} - \frac{2}{100}}{2500} \right) = \frac{9.8 \cdot 2}{2500 - 0.00315} = 0.00313
\]

\[
cost = \frac{V_{TRB} \times \text{unit cost}}{100 \text{ ft of levee station}}
\]

\[
= 55,200 \text{ cu yd} / 100 \text{ ft} \times 8.120 = $64,200 / 100 \text{ ft}
\]

E63
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. by WCS/RWC

Cutoff analysis

\[ x_1 = 7.80 \text{ ft}; \quad x_3 = 450 \text{ ft}; \quad \beta_1 = \rho_1 \gamma \nu; \quad Q_s = \frac{\beta_2 H}{2} \]

where \( \Sigma \Phi_m = \Phi_1 + \Phi_2 + \Phi_3 + \Phi_4 + \Phi_5 \)

and \( \Phi_1 = 0, \quad \Phi_2 = \frac{x_1}{D} = \frac{7.80}{100} = 7.8, \quad \Phi_3 = 0 \)

\[
\Phi_2 = \ln \left( \frac{1}{1 - \frac{d_c}{D}} \right) + \frac{x_3 - x_2}{D} = \ln \left( \frac{1}{1 - \frac{d_c}{D}} \right) + \frac{450}{100} - \frac{d_c}{D}
\]

\[
\Phi_4 = \ln \left( \frac{1}{1 - \frac{d_c}{D}} \right) + \frac{x_3 - x_2}{D} = \ln \left( \frac{1}{1 - \frac{d_c}{D}} \right) + \frac{450}{100} - \frac{d_c}{D}
\]

<table>
<thead>
<tr>
<th>( \frac{d_c}{D} )</th>
<th>( \Phi_2 )</th>
<th>( \frac{1}{1 - \frac{d_c}{D}} )</th>
<th>( \ln \left( \frac{1}{1 - \frac{d_c}{D}} \right) )</th>
<th>( 2.2 - \frac{d_c}{D} )</th>
<th>( \Phi_3 )</th>
<th>( 4.5 - \frac{d_c}{D} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>7.8</td>
<td>2.00</td>
<td>0.093</td>
<td>1.7</td>
<td>2.693</td>
<td>4.0</td>
</tr>
<tr>
<td>0.6</td>
<td>7.8</td>
<td>2.56</td>
<td>0.116</td>
<td>1.4</td>
<td>2.516</td>
<td>3.7</td>
</tr>
<tr>
<td>0.7</td>
<td>7.8</td>
<td>3.33</td>
<td>1.204</td>
<td>1.5</td>
<td>2.704</td>
<td>3.8</td>
</tr>
<tr>
<td>0.8</td>
<td>7.8</td>
<td>5.00</td>
<td>1.607</td>
<td>1.4</td>
<td>3.009</td>
<td>3.7</td>
</tr>
<tr>
<td>0.9</td>
<td>7.8</td>
<td>10.00</td>
<td>2.303</td>
<td>1.3</td>
<td>3.603</td>
<td>3.6</td>
</tr>
<tr>
<td>0.95</td>
<td>7.8</td>
<td>20.00</td>
<td>2.996</td>
<td>1.25</td>
<td>4.246</td>
<td>3.52</td>
</tr>
</tbody>
</table>

\[ \frac{d_c}{D} \] | \( \Phi_4 \) | \( \Sigma \Phi_m \) | \( Q_s \) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>4.693</td>
<td>14.586</td>
<td>247 qpm/100 ft levee station</td>
</tr>
<tr>
<td>0.6</td>
<td>4.810</td>
<td>15.502</td>
<td>245</td>
</tr>
<tr>
<td>0.7</td>
<td>5.004</td>
<td>15.508</td>
<td>237</td>
</tr>
<tr>
<td>0.8</td>
<td>5.309</td>
<td>16.118</td>
<td>228</td>
</tr>
<tr>
<td>0.9</td>
<td>5.902</td>
<td>17.304</td>
<td>213</td>
</tr>
<tr>
<td>0.95</td>
<td>6.542</td>
<td>18.591</td>
<td>193</td>
</tr>
</tbody>
</table>

E64
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 3 by WCS/RWE

Cut off analysis (cm^4)

Equations for head

\[ h_a = H \left(1 - \frac{\phi_3}{2\phi_m}\right) = 25 \left(1 - \frac{1.8}{2\phi_m}\right) \]

\[ h_b = h_a - \frac{L_2}{L_2 + a_c} (h_a - h_c) \]

\[ h_c = H \left(1 - \frac{\phi_3 + \phi_2}{2\phi_m}\right) \]

\[ h_d = h_c \left(1 - \frac{a_c}{4 + a_3}\right) \]

\[ M = \frac{h_a - h_b}{L_2} = \frac{h_a - h_b}{220}; \quad i = \frac{h_d}{L_2} + \frac{h_d}{a_2} \]

<table>
<thead>
<tr>
<th>dc/D</th>
<th>h_a</th>
<th>h_c</th>
<th>h_a-h_c</th>
<th>h_b</th>
<th>h_d</th>
<th>i</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>11.900</td>
<td>7.581</td>
<td>4.319</td>
<td>8.678</td>
<td>7.093</td>
<td>1.18</td>
<td>0.0149</td>
</tr>
<tr>
<td>0.6</td>
<td>12.028</td>
<td>8.009</td>
<td>4.019</td>
<td>8.570</td>
<td>7.067</td>
<td>1.18</td>
<td>0.0143</td>
</tr>
<tr>
<td>0.7</td>
<td>12.426</td>
<td>8.067</td>
<td>4.359</td>
<td>7.119</td>
<td>6.981</td>
<td>1.14</td>
<td>0.0150</td>
</tr>
<tr>
<td>0.8</td>
<td>12.902</td>
<td>8.234</td>
<td>4.668</td>
<td>9.479</td>
<td>6.991</td>
<td>1.14</td>
<td>0.0165</td>
</tr>
<tr>
<td>0.9</td>
<td>13.731</td>
<td>8.227</td>
<td>5.204</td>
<td>10.033</td>
<td>7.106</td>
<td>1.18</td>
<td>0.0168</td>
</tr>
<tr>
<td>0.95</td>
<td>14.511</td>
<td>8.801</td>
<td>5.710</td>
<td>10.824</td>
<td>7.267</td>
<td>1.21</td>
<td>0.0181</td>
</tr>
</tbody>
</table>

Cost for cut off, dc/D = 0.95

\[ dc + \phi = 0.95 \times 100 + 2 = 101 \text{ ft} \]

Area \(2.02 / \text{ft}^2 \times 65 \times 100 = 6500 \text{ ft}^2\)

\[ \text{cost} = 6500 \times 3.00 = 19,500 \]

Area \(2.02 / \text{ft}^2 \times (101 - 65) \times 100 = 3600 \text{ ft}^2\)

\[ \text{cost} = 3600 \times 3.00 = 2,760 \]

Cut off total cost = \$48,300/100 ft of levee station
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 3 by RWC

Date \text{July 25/66}

Page 10 of 24

Pervious top stratum, infinite landslide

\begin{equation}
H = 25 \text{ ft} \\
D = 100 \text{ ft} \\
\chi = 1000 \times 10^{-4} \text{ cm/sec} \\
\ell = 0.3 \\
R_S = 1.5 \\
R_w = 1 \text{ ft}
\end{equation}

Relief well design \[P = 0.25\]

Note: References to Figs. 60 & 61 are from USACEwes TM 3-424.

Labeled steps follow those given in TM 3-424 beginning on page 3

a) \[h_a = h_o \chi = 0.153 \chi \approx 3.19 \text{ ft}\]

b) \[h_w = h_a = 3.19 \text{ (assumed)}\]

\[\Delta M = \frac{H - h_w}{3} - \frac{h_w}{\chi} = \frac{25 - 3.19}{1000} - \frac{3.19}{447} = 0.01471\]

c) \[\text{Assume } a = 100 \text{ ft}\]

\[Q_w = \frac{14.72 \times a \Delta M}{D} \]

\[= 14.72 \times (100)(0.01471)(a)(100) = 2.179 \text{ pm}\]

d) From Fig. 61, \[h_w = 0.61 \text{ ft}\]

e) \[h_w = h_a - h_w = 3.19 - 0.61 = 2.58 \text{ ft}\]

f) \[\Theta_w = \frac{h_w}{a \Delta M} = \frac{2.57}{a(0.01471)} = 114.7 \frac{a}{\Theta_w}\]

\begin{tabular}{c|c|c}
\(a\) & \(\Theta_w\) \\
1.75 & 2.32 \\
1.75 & 2.32 \\
1.25 & 1.40
\end{tabular}
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 3 by Ruw

Date 8/15/64

Page 11 of 20

Relief well design (cont.)

P = 0.25 (con't)

g) uw = 15 ft (assumed)

\[ D = 100 \text{ ft} \]

<table>
<thead>
<tr>
<th>a</th>
<th>uw</th>
<th>D/a</th>
<th>( \Theta_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>75</td>
<td>1.53</td>
<td>1.44</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>1.00</td>
<td>1.50</td>
</tr>
<tr>
<td>125</td>
<td>125</td>
<td>0.80</td>
<td>1.57</td>
</tr>
</tbody>
</table>

h) By inspection \( \Theta_w = 1.16 \)

By interpolation, 1st trial well spacing \( a = 100 + 25 \left( \frac{11}{35} \right) = 108 \text{ ft} \)

i) from fig. 60, \( \Theta_w \) for \( a/2w = 0.81, \ D/a = 0.93 \)

\[ \Theta_w = 1.80 \]

j) \( \Theta_w = 1.84 \) (assumed) : Repeat steps c) to i) using \( a = 108 \text{ ft} \)

k) \( \Theta_w = 14.72 \times \Delta AM + \Delta D = 14.72 \left( 0.017 \right) (0.01471)(0.1)(100) \]

\[ = 234 \text{ gpm} \]

l) from fig. 61, \( H_w = 0.04 \text{ ft} \)

m) \( h_w = H_w - H_w^2 = 3.18 - 0.04 = 3.14 \text{ ft} \)

n) \( \Theta_w = h_w/\Delta AM = \frac{2.54}{a(0.01471)} = \frac{172.7}{a} \)

<table>
<thead>
<tr>
<th>a</th>
<th>( \Theta_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>1.92</td>
</tr>
<tr>
<td>100</td>
<td>1.73</td>
</tr>
<tr>
<td>110</td>
<td>1.57</td>
</tr>
</tbody>
</table>

o) from fig. 60, \( \Theta_w = 1.84 \)

By interpolation, 2nd trial well spacing \( a = 90 + 10 \left( \frac{8}{9} \right) \)

\[ = 94 \text{ ft} \]

p) from fig. 60, \( \Theta_w = 94, \ D/a = 1.00 \); \( \Theta_w = 1.78 \)

q) \( \Theta_w = 1.84 \) (assumed) : Repeat steps c) to i) using \( a = 94 \text{ ft} \)
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 3 by RWC

Date 6/25/66
Page 12 of 20

Relief well design (cont.)  \( P = 0.25 \) (cont.)

\( c_3 \) \( Q_w = 14.72 \times \Delta M \times k \times D = 14.72 \times (0.01471)(0.1)(100) \)

\( = 204.9 \text{ gpm} \)

\( d_3 \) from fig. 61, \( H_w = 0.60 \text{ ft} \)

\( e_3 \) \( h_w = H_w - H_u = 3.1 - 0.60 = 2.5 \text{ ft} \)

\( f_3 \) \( \Theta_w = h_w / \Delta M = 2.58 \text{ ft} / 0.01471 \text{ ft} = 175.4 \text{ gpm} / a \)

\[ \begin{array}{c|c|c|c|c|c} a & \Theta_w & \text{a} & \text{a} / h_w & \text{D/a} & \Theta_w \\ \hline 90 & 1.95 & 90 & 1.11 & 1.11 & 1.95 \\ 100 & 1.75 & 100 & 1.00 & 1.00 & 1.75 \\ 110 & 1.59 & 110 & 0.91 & 0.91 & 1.59 \end{array} \]

\( h_3 \) By inspection \( \Theta_w = 1.85 \)

By interpolation 3rd trial well spacing \( a = 90 + 10 \times (0.02, 0) \)

\( = 95 \text{ ft} \)

Compare 95 ft with 2nd trial 94 ft - good enough

\( a_{sel} = 95 \text{ ft} \)

\( Q_w = 14.72 \times (a)(\Delta M)(k)(D) \)

\( = 14.72 \times (95)(0.01471)(0.1)(100) = 206.9 \text{ gpm} \)

\( \bar{W} = 25 \text{ ft} \)

Cost per well using plastic pipe and screen:

\( C_w = (\bar{D} + \bar{R}) \times \bar{L} + (\bar{D} + \bar{W} + \bar{F} + \bar{L}) \bar{W} + \bar{G} + \bar{W} + \bar{C} + \bar{W} \)

\( = (20 + 30) \times 6 + (16 + 85 + 12) \times 25 + 400 + 300 + 1000 \)

\( = \$4925 \)

Cost per 100 ft levee station

\( C_{ws} = C_w \times (100/a_{sel}) = 4925 \times (100/95) = \$5179 / 100 \text{ ft} \)
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 3 by Quic

Date 8/25/66
Page 13 of 20

Relief well design (cont.)  \( R = 0.375 \)

a) \( h_a = L_x x_k = 0.53(6) = 3.18 \text{ ft} \)

b) Assume \( H_w = h_a = 3.18 \text{ ft} \)

\[
\Delta M = \frac{H - H_w}{S} = \frac{25 - 3.18}{1000} = 0.00471
\]

c) Assume \( a = 100 \text{ ft} \); \( Q_w = 14.72 \text{ gpm ft} \)

\[
= 14.72(100)(0.00471)(0.1)(100) = 2.179 \text{ gpm}
\]

d) From fig. 61, \( H_w = 0.62 \text{ ft} \)

e) \( h_{aw} = H_w = 3.18 - 0.62 = 2.56 \text{ ft} \)

f) \( \Theta_{aw} = \frac{h_{aw}}{\Delta M} = \frac{2.56}{0.00471} = 174.0 \)

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \Theta_{aw} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1.74</td>
</tr>
<tr>
<td>125</td>
<td>1.39</td>
</tr>
<tr>
<td>150</td>
<td>1.16</td>
</tr>
</tbody>
</table>

\[ \Theta_{aw} = 1.25 \]

\[ \Theta_{aw} = 1.33 \]

\[ \Theta_{aw} = 1.33 < \Theta_{aw} = 1.33 \quad \text{Proceed with steps k) to m)} \]

k) Assume \( H_w = h_a = 3.18 \text{ ft} \); \( \Delta M = 0.00471 \) from b)

l) \( Q_w = 14.72 \text{ gpm ft} \)

\[
= 14.72(140)(0.00471)(0.1)(100) = 3.039 \text{ gpm}
\]

From fig. 61, \( H_w = 0.74 \text{ ft} \)

m) \( h_{aw} = H_w - H_w = 3.18 - 0.74 = 2.44 \text{ ft} \)
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 3 by WWC

Levee Underseepage Computer Program

P = 0.375 (cont')

h) $h_a = h_m (\theta_m / \theta_a) = 2.44 (1.25/1.33) = 2.29 \text{ ft}$

o) $H_a = h_a + H_w = 2.29 + 0.74 = 3.03 \text{ ft}$

p) $\Delta M = \frac{H - H_a}{x} - \frac{H_a}{x} = \frac{25 - 3.03}{10.00} - \frac{3.03}{10.00} = 0.01519$

q) $\theta_m = h_m / \Delta M = \frac{2.44/(0.01519)}{2.29} = \frac{160.6}{2.29}$

r) from fig. 60,

<table>
<thead>
<tr>
<th>a</th>
<th>$a/gw$</th>
<th>$D/a$</th>
<th>$\theta_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>120</td>
<td>0.65</td>
<td>1.28</td>
</tr>
<tr>
<td>130</td>
<td>130</td>
<td>0.70</td>
<td>1.31</td>
</tr>
<tr>
<td>140</td>
<td>140</td>
<td>0.71</td>
<td>1.33</td>
</tr>
</tbody>
</table>

s) By inspection, $\theta_m = 1.29$

By interpolation, 2nd trial well spacing $a = 120 + 10(5/10) = 125 \text{ ft}$

t) from fig. 60, $\theta_a$ for $a/gw = 125, D/a = 0.65$

$\theta_a = 1.24$

u) Compare $a = 125 \text{ ft}$ with previous $a = 140 \text{ ft}$

(Repeat steps b) to m) using $a = 125 \text{ ft}$

$\theta_a = 1.24$

$\theta_m = 1.29$

v) $H_m = 3.18, \Delta M = 0.0147$

$Q_w = 14.72 \times \Delta M / D$

$= 14.72(3.18)(0.0147)(0.1)(100) = 27.1 \text{ q pm}$

w) from fig. 61, $H_w = 0.66 \text{ ft}$

x) $h_m = H_m - H_w = 3.18 - 0.66 = 2.49 \text{ ft}$

y) $h_a = h_m (\theta_a / \theta_m) = 2.49 (1.24/1.29) = 2.39 \text{ ft}$

z) $H_a = h_a + H_w = 2.39 + 0.66 = 3.05 \text{ ft}$

E70
Levee Underseepage Computer Program
Hand Computations used for Verification
Cross Section No. 3 by RNC

Date 8/25/86
Page 15 of 20

Relief well design (cm^2)

p2) \[ \Delta M = \frac{H - H_{aw}}{S} - \frac{H_{aw}}{x_3} = \frac{25 - 3.02}{1000} - \frac{3.08}{447} = 0.01503 \]

q2) \[ \Theta_m = \frac{h_m}{\Delta M} = \frac{2.49}{2.0} (0.01503) = \frac{16.57}{a} \]

\[ \begin{array}{ccc}
\text{a} & \text{a/aw} & \text{D/a} & \Theta_m \\
120 & 120 & 0.83 & 1.28 \\
130 & 130 & 0.77 & 1.31 \\
\end{array} \]

r2) By inspection \( \Theta_m = 1.30 \)

By interpolation outside well spacing \( a = 120 + 10 (\%i) = 127 \text{ ft} \)

Compare \( a = 127 \text{ ft} \) with \( a = 125 \text{ ft} \)

s2) From fig. 60, \( \Theta_w \) for \( a/aw = 127, D/a = 0.79 \)

\( \Theta_w = 1.24 \)

u) Repeat steps r3 to t) using \( a = 127 \text{ ft} \)

\( \Theta_w = 1.24 \)

\( \Theta_m = 1.30 \)

k3) \( h_m = 3.18 \); \( \Delta M = 0.01471 \)

\[ Q_m = 14.72 \text{ a } 4.7 \text{ ft} \]

\( = 14.72 (1.27)(0.01471)(0.1)(100) = 275 \text{ gpm} \)

l3) From fig. 61, \( H_w = 0.70 \text{ ft} \)

m3) \( h_m = H_m - H_w = 3.18 - 0.70 = 2.48 \text{ ft} \)

n3) \( h_m = h_m(\Theta_w/\Theta_m) = 2.48(1.24/1.30) = 2.37 \)

o3) \( H_m = h_m + H_w = 2.37 + 0.70 = 3.07 \)

p3) \[ \Delta M = \frac{H - H_{aw}}{S} - \frac{H_{aw}}{x_3} = \frac{25 - 2.07}{1000} - \frac{3.07}{447} = 0.01506 \]
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 3 by RWC

Date 8/25/66
Page 16 of 20

Relief well design (cont.) \( P = 0.375 \) (cont'd)

\( q_3 \) \( \Theta_m = \frac{h_m}{a_{nH}} = 2.4q/a(0.01506) = \frac{164.7}{a} \)

\( a \quad \Theta_m \)
\( \frac{120}{130} \quad 1.37 \quad 1.27 \)

\( a_4 \) from fig. 120, \( a/a_{nH} \) \( \frac{120}{130} \) \( 0.73 \quad 1.28 \)
\( 130 \)

\( \Theta_m \) \( 1.31 \)

\( \Theta_m \) By inspection \( \Theta_m = 1.30 \)
By interpolation 4th trial well spacing \( a = 120 + 10(7/3) \)
\( = 127 \) ft

Compare \( a_4 = 127 \) with \( a_3 = 127 \)

\( a_{set} = 127 \) ft

\( Q_w = 14.72 \) cfm \( \times D \)
\( = 14.72(127)(0.01506)(0.1)(100) = 2829 \) gpm

\( \bar{W} = 3.75 \) ft

Cost per well (using plastic pipe and screen)

\( C_W = (D_R + R_P) \bar{W} + (D_R + W + P_L) \bar{W} + B_F + W_C + W_D \)
\( = (20 + 30) \bar{W} + (16 + 65 + 12) \bar{W} + 400 + 300 + 1000 \)
\( = \$ 6237 \)

Cost per 100 ft of levee station

\( C_{WS} = C_W \left( \frac{100}{a_{set}} \right) = 6237 \left( \frac{100}{127} \right) = \$ 4911/100 \) ft
Levee Underseeage Computer Program

Hand Computations used for Verification

Cross Section No. 3 by RWC

Date 5/25/76
Page 11 of 20

Reinforced design (cont.) P<0.50

a) \( h_C = i_C \times = 0.53 \times = 3.18 \text{ ft} \)

b) Assume \( h_{aw} = h_C = 3.18 \text{ ft} \)

\[
AM = \frac{H - H_{aw}}{2} - \frac{H_{aw} - H_{aw}}{x_3} = \frac{25 - 3.18}{100} = \frac{3.18}{447} = 0.01471
\]

c) Assume \( a = 150 \text{ ft} \)

\[
Q_w = (14.72 \times AM \times k_x) = 14.72(150)(0.01471)(0.1)(100) = 325 \text{ qfpm}
\]

d) From fig. 60, \( H_w = 0.78 \)

e) \( H_{aw} = h_{aw} + H_w = 3.18 + 0.78 = 2.40 \text{ ft} \)

f) \( \theta_{aw} = \frac{h_{aw} / AM}{a} = \frac{2.40}{a(0.01471)} = 16.8 \frac{2}{a} \)

\[
\begin{array}{|c|c|c|c|}
\hline
a & \theta_{aw} \\
\hline
125 & 1.31 \\
150 & 1.09 \\
175 & 0.93 \\
\hline
\end{array}
\]

g) From fig. 60, \( a \theta_{aw} = \theta_w \)

\[
\begin{array}{|c|c|c|c|}
\hline
a & \theta_{aw} & D/K & \theta_w \\
\hline
125 & 1.31 & 0.40 & 0.96 \\
150 & 1.09 & 0.67 & 0.97 \\
175 & 0.93 & 0.57 & 0.99 \\
\hline
\end{array}
\]

h) By inspection \( \theta_{aw} = 0.98 \)

By interpolation 1st trial well spacing \( a = 150 + 25(11/16) = 167 \text{ ft} \)

i) From fig. 60, \( \theta_m \) for \( q/w = 167, D/K = 0.40 \)

\( \theta_m = 1.09 \)

j) \( \theta_w = 0.96 < \theta_m = 1.09 \) - Proceed with steps k) to n)

k) Assume \( H_{aw} = h_C = 3.18 \text{ ft} \), \( AM = 0.01471 \) from b)

\[
Q_w = 14.72 \times AM \times k_x D
\]

\[
= 14.72(167)(0.01471)(0.1)(100) = 362 \text{ qfpm}
\]

E73
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 3

Date 6/25/66

Page 18 of 20

Relief well design (cm.³)

\[ P = 0.50 \text{ (cm.³)} \]

1) from fig. 61, \( H_w = 0.85 \text{ ft} \)

2) \( H_m = H_w - H_w = 3.18 - 0.85 = 2.33 \text{ ft} \)

3) \( h_m = h_m (\theta_w/\theta_m) = 2.33 (0.08/10) = 0.90 \text{ ft} \)

4) \( H_{aw} = h_m + H_w = 2.09 + 0.85 = 2.94 \text{ ft} \)

5) \( \Delta M = \frac{H_{aw} - H_w}{\theta_m} = \frac{2.94 - 0.85}{1000} = \frac{2.09}{441} = 0.01548 \)

6) \( \theta_m = h_m/\Delta M = 2.33/0.01548 = \frac{150.5}{a} \)

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>1.07</td>
</tr>
<tr>
<td>150</td>
<td>1.00</td>
</tr>
<tr>
<td>160</td>
<td>0.94</td>
</tr>
</tbody>
</table>

7) from fig. 60,

\[ a \frac{u_{aw}}{d_a}; \theta_m \]

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>1.11</td>
</tr>
<tr>
<td>150</td>
<td>0.97</td>
</tr>
<tr>
<td>160</td>
<td>0.87</td>
</tr>
<tr>
<td>175</td>
<td>0.83</td>
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</table>

8) By inspection \( \theta_m = 1.06 \)

By interpolation 2nd trial well spacing \( a_i = 140 + 10 (141) \)

9) from fig. 60, \( \theta_w \) for \( a_{aw} = 141 \), \( \theta_w = 0.71 \)

10) \( \theta_w = 0.95 \)

11) Repeat steps 1) to 9) using \( a = 141 \text{ ft} \)

12) \( H_m = 3.18; \Delta M = 0.01471 \)

\[ Q_w = 14.72 a \Delta M \text{ ft}^2 \text{D} \]

\[ = 14.72 (141)(0.01471)(0.1)(103) = 305 \text{ gpm} \]

13) from fig. 61, \( H_w = 0.75 \text{ ft} \)

14) \( h_m = H_m - H_w = 3.18 - 0.75 = 2.43 \text{ ft} \)
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 3 by RUK

Date: 6/25/66

Page: 19 of 20

Relief well design (cont.)

\[ h_2 = h_m \left( \frac{\Theta_m}{\Theta_m} \right) = 2.43 \left( \frac{0.95}{1.06} \right) = 2.18 \text{ ft} \]

\[ h_2 = h_m + h_w = 2.18 + 0.75 = 2.93 \text{ ft} \]

\[ \Delta M = \frac{H - h_2}{x} = \frac{25 - 2.93}{100} = 0.0155 \text{ ft} \]

\[ \Theta_m = \frac{h_m/\Delta M}{a} = \frac{2.43/0.01552}{a} = \frac{156.6}{a} \]

\[ \theta_m \]

<table>
<thead>
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<th>( \Theta_m )</th>
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<tbody>
<tr>
<td>140</td>
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</tr>
<tr>
<td>150</td>
<td>0.04</td>
</tr>
<tr>
<td>160</td>
<td>0.08</td>
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</table>

\[ r_2 \] from fig. 60, \( \alpha \) \begin{align*} \frac{h_m}{\Delta M} & \quad \frac{D}{\alpha} \quad \Theta_m \end{align*} \begin{align*} 140 & \quad 0.71 & \quad 1.05 \\ 150 & \quad 0.67 & \quad 1.04 \\ 160 & \quad 0.63 & \quad 1.03 \end{align*}

\[ s_2 \] By inspection \( \Theta_m = 1.06 \)

By interpolation 3rd trial well spacing \( a_2 = 140 + 10(0.6) \)

\[ = 147 \text{ ft} \]

Compare \( a_2 = 147 \text{ with } a_1 = 141 \text{ ft} \)

\[ t_2 \] from fig. 60, \( \Theta_w \) for \( h_m = 147 \), \( D/\alpha = 0.68 \)

\[ \Theta_w = 0.96 \]

\[ m_3 \] Repeat steps \( k \) to \( t \) using \( a = 147 \text{ ft} \)

\[ \Theta_w = 0.96 \]

\[ \Theta_m = 1.04 \]

\[ k_3 \] \( h_m = 3.18 \) \( \Delta M = 0.01471 \)

\[ Q_w = \frac{14.72a \Delta M}{D} = 14.72(147)(0.01471)(0.1)(100) \approx 31.24 \text{ cfm} \]

\[ l_3 \] from fig. 61, \( h_w = 0.77 \text{ ft} \)

\[ m_3 \] \( h_m = H_m - h_w = 3.18 - 0.77 = 2.41 \text{ ft} \)

\[ n_3 \] \( h_w = h_m (\Theta_w/\Theta_m) = 2.41 \left( \frac{0.96}{1.06} \right) = 2.18 \text{ ft} \)

\[ o_3 \] \( h_w = h_m + h_w = 2.18 + 0.77 = 2.95 \text{ ft} \)
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 3 by R.W.

Date 8/25/66
Page 27 of 20

Relief well design (cont'd) \( P = 0.50 \) (cont'd)

\[ \Delta M = H - H_{aw} \]
\[ = 25 - 2.95 = 0.01545 \]

\[ \Theta_m = \frac{h_m}{a} \Delta M = 2.41/6(0.01545) < \frac{1560}{a} \]

\[ a \] \hspace{1cm} \[ \Theta_m \]

140 \hspace{1cm} 1.11
150 \hspace{1cm} 1.04

\[ \theta_m = 1.04 \]

By interpolation 4th trial well spacing \( a_4 = 140 + 10(5/1) = 147 \) ft

Compare \( a_4 = 147 \) with \( a_3 = 147 \) ft

\[ a_{sel} = 147 \] ft

\[ Q_w = 14.72 \] ft \( \Delta M \) ft \( D \)

\[ = 14.72(147)(0.01545)(0.0)(10) = 336.9 \] ft

\[ \bar{w} = 50 \] ft

Cost per well (using plastic pipe and screen)

\[ C_W = (D_R + RP) \bar{w} + (D_{RP} + WS + FL) \bar{w} + BF + WC + WD \]

\[ = (20 + 30) \bar{w} + (16 + 65 + 12) \bar{w} + 400 + 300 + 100 \]

\[ = 7650 \]

Cost per 100 ft of levee station

\[ C_{WS} = C_W (100/a_{sel}) = 7650 \left( \frac{100}{147} \right) = 5204 \]
PROJECT NAME: PROGRAM DEVELOPMENT
STATION: X-SECT. 3

GENERAL CONTROL MEASURE INPUT DATA

<table>
<thead>
<tr>
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<th>Value</th>
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</tr>
<tr>
<td>H</td>
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</tr>
<tr>
<td>LTO</td>
<td>120</td>
</tr>
<tr>
<td>RTD</td>
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</tr>
<tr>
<td>L1</td>
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</tr>
<tr>
<td>L3</td>
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</tr>
<tr>
<td>D</td>
<td>100</td>
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</tr>
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<td>KBR</td>
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<tr>
<td>ZT</td>
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<tr>
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<tr>
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SUBWTR = 50. LB/CU FT

SUPPLEMENTAL CONTROL MEASURE INPUT DATA

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<tr>
<td>IOB</td>
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<tr>
<td>M1</td>
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RIVERSIDE BLANKET

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<tr>
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<td>M3R</td>
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<tr>
<td>M4</td>
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CUTOFF

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RELIEF WELL

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<tr>
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<td>J</td>
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<td>HEL</td>
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**PROJECT NAME:** PROGRAM DEVELOPMENT  
**STATION:** X-SECT. 3  

LEVEE UNDERSEEPAGE ANALYSIS  
**INITIAL CONDITIONS**

<table>
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<tr>
<td>X3</td>
<td>447. FT</td>
</tr>
<tr>
<td>M</td>
<td>.1725E-01</td>
</tr>
<tr>
<td>I</td>
<td>1.286</td>
</tr>
<tr>
<td>QS</td>
<td>254. GPM/100 FT</td>
</tr>
<tr>
<td>HO</td>
<td>7.7 FT</td>
</tr>
<tr>
<td>$</td>
<td>.6901E-01</td>
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</table>

---

**Head Calculations**

- X1 = 782. FT
- X3 = 447. FT
- M = .1725E-01
- I = 1.286
- QS = 254. GPM/100 FT
- HO = 7.7 FT
- $ = .6901E-01
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 3

OUTPUT DATA FOR BERM ANALYSIS

IMPERVIOUS BERM

\[
X_1 = 702. \text{ FT} \\
X_3 = \text{UNDEFINED} \\
M = \text{UNDEFINED} \\
I = \text{UNDEFINED} \\
Q_s = \text{UNDEFINED}
\]

\[
X_1 = 400. \text{ FT} \\
T = 9.8 \text{ FT} \\
VB = 9404. \text{ CU YD/100 FT LEVEE STATION}
\]

BERM COST CALCULATION

IMPERVIOUS BERM

\[
VB = 9404. \text{ CU YD/100 FT LEVEE STATION} \\
\text{UNIT COST} = \$ \ 1.30 /\text{CU YD} \\
\text{TOTAL COST} = \$ \ 12225.00 /100 \text{ FT LEVEE STATION}
\]
PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 3

OUTPUT DATA FOR BERM ANALYSIS

SEMIPERVIOUS BERM

\[
\begin{align*}
X_1 &= 782. \text{ FT} \\
X_3 &= \text{UNDEFINED} \\
M &= \text{UNDEFINED} \\
I &= \text{UNDEFINED} \\
Q_0 &= \text{UNDEFINED} \\
X_{SP} &= 313. \text{ FT} \\
T &= 8.1 \text{ FT} \\
V_B &= 6247. \text{ CU YD/100 FT LEVEE STATION}
\end{align*}
\]

Hand Calculations

BERM COST CALCULATION

SEMIPERVIOUS BERM

\[
\begin{align*}
V_B &= 6247. \text{ CU YD/100 FT LEVEE STATION} \\
\text{UNIT COST} &= \$ 1.30 /\text{CU YD} \\
\text{TOTAL COST} &= \$ 8120.00 /100 \text{ FT LEVEE STATION}
\end{align*}
\]

\$8120
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 3

OUTPUT DATA FOR BERM ANALYSIS

PERVIOUS BERM WITH COLLECTOR PIPE

\[ x_1 = 702. \text{ FT} \]
\[ x_3 = \text{UNDEFINED} \]
\[ m = \text{UNDEFINED} \]
\[ i = \text{UNDEFINED} \]
\[ q_s = \text{UNDEFINED} \]

\[ x_p = 212. \text{ FT} \]
\[ t = 6.1 \text{ FT} \]
\[ v_b = 3387. \text{ CU YD/100 FT LEVEE STATION} \]

BERM COST CALCULATION

PERVIOUS BERM WITH COLLECTOR PIPE

\[ v_b = 3387. \text{ CU YD/100 FT LEVEE STATION} \]
\[ \text{UNIT COST} = ? \text{ NO RECENT CONSTRUCTION EXPERIENCE} \]
\[ \text{TOTAL COST} = ? \text{ NO RECENT CONSTRUCTION EXPERIENCE} \]
PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 3

OUTPUT DATA FOR BERM ANALYSIS

SAND BERM

X1 = 782. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED

XS = 279. FT
T = 7.4 FT
VB = 5203. CU YD/100 FT LEVEE STATION

BERM COST CALCULATION

SAND BERM

VB = 5203. CU YD/100 FT LEVEE STATION
UNIT COST = $ 3.75 /CU YD
TOTAL COST = $ 19512.00 /100 FT LEVEE STATION

Hand Calculations

E86
PROJECT: PROGRAM DEVELOPMENT  
STATION: X-SECT. 3  

OUTPUT DATA FOR BLANKET ANALYSIS  

\[ \begin{align*}  
X_1 &= 1995. \text{ FT} \\
X_3 &= 447. \text{ FT} \\
M &= 0.9392 \times 10^{-2} \\
I &= 700 \\
Q_s &= 138. \text{ GPM/100 FT} \\
X_R &= 1995. \text{ FT} \\
L_B &= 2500. \text{ FT} \\
K_B &= 0.9067 \times 10^{-5} \text{ CM/S} \\
Z_B &= 6.0 \text{ FT} \\
K_{BB} &= 0.1535 \times 10^{-4} \text{ CM/S} \\
Z_{BB} &= 12.0 \text{ FT} \\
V_{RB} &= 55556. \text{ CU YD/100 FT LEVEE STATION} 
\end{align*} \]

IF XR OR LB > DISTANCE TO RIVER, SOLUTION INFEASIBLE

\[ \begin{align*}  
\text{Hand Calculations} \\
\text{1994} \\
\text{447} \\
0.00939 \\
0.7 \\
138 \\
1994 \\
2500 \\
0.09 \times 0.04 \\
6 \\
\text{55556. CU YD/100 FT LEVEE STATION} \\
\end{align*} \]

BLANKET COST CALCULATION  

\[ \begin{align*}  
\text{VOLUME} &= 55556. \text{ CU YD/100 FT LEVEE STATION} \\
\text{UNIT COST} &= \$ 1.20 /\text{CU YD} \\
\text{COST} &= \$ 66666.00 /100 \text{ FT OF LEVEE STATION} 
\end{align*} \]
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 3

OUTPUT DATA FOR BLANKET CALCULATION

TRIANGULAR BLANKET

X1 = UNDEFINED
X3 = 447. FT
M = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED

XR = 1995. FT
LB = 2500. FT
KB = .5000E-05 CM/S
ZB = 9.8 FT

VRB = 55419. CU YD/100 FT LEVEE STATION

IF XR OR LB = DISTANCE TO RIVER, SOLUTION INFEASIBLE

BLANKET COST CALCULATION

TRIANGULAR BLANKET

VRB = 55419. CU YD/100 FT LEVEE STATION
UNIT COST = $ 1.20 /CU YD
TOTAL COST = $ 66502.00 /100 FT OF LEVEE STATION

E89
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 3

OUTPUT DATA FOR CUTOFF ANALYSIS

 DC/D =  .950
 X1 =  782. FT
 X3 =  447. FT
 M =  .1813E-01
 I =  1.205
 Qs =  198. GPM/100 FT

CUTOFF COST CALCULATION

 DEPTH =  101. FT
 COST = $ 48300.00 /100 FT OF LEVEE STATION

Hand Calculations
**PROJECT:** PROGRAM DEVELOPMENT  
**STATION:** X-SECT. 3  

**OUTPUT DATA FOR RELIEF WELL ANALYSIS**  

<table>
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| .375| 125  | 38   | 275.40| $4995.00 |

*Hand Calculations*

**254**
Cross Section 4
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 4 by RUC

Date 8/2/54

Page 1 of 18

Previous top stratum, open exit

H = 25.5 ft
L1 = 98.0 ft
L2 = 220 ft
L3 = 506 ft

D1 = 103 ft
D2 = 68 ft
D3 = 68 ft

\[ \chi_1 = \frac{\text{Tan}h \left( \frac{C_{uh} L1}{C_{um}} \right)}{C_{um}} \]

where

\[ C_{uh} = \left( \frac{k_{uh} e}{k D_{um} D} \right)^{1/2} \]

\[ = \left( \frac{0.5 \times 10^{-4}}{1000 \times 10^{-4} \times L \times 100} \right)^{1/2} \]

\[ = 0.000913 \]

\[ \chi_1 = \frac{\text{Tan}h \left( \frac{0.000913 \times 98.0}{0.000913} \right)}{0.000913} = 7.80 \text{ ft} \]

\[ \chi_2 = \frac{\text{Tan}h \left( \frac{C_{uc} L2}{C_{ue}} \right)}{C_{ue}} \]

where

\[ C_{ue} = \left( \frac{k_{ue} e}{k D_{ue} D} \right)^{1/2} \]

\[ = \left( \frac{3 \times 10^{-4}}{1000 \times 10^{-4} \times L \times 100} \right)^{1/2} \]

\[ = 0.002236 \]

\[ \chi_2 = \frac{\text{Tan}h \left( \frac{0.002236 \times 220}{0.002236} \right)}{0.002236} = 3.60 \text{ ft} \]

\[ h_0 = \frac{H \chi_2}{\chi_1 + L2 + \chi_3} = \frac{25 \times (360)}{780 + 220 + 360} = 6.64 \text{ ft} \]

\[ i = \frac{h_0}{z_x} = \frac{6.64}{6} = 1.10 \]

\[ \therefore \ i = 0.3 \]

E94
Initial condition calculations (cm*)

\[ M = \frac{H}{x_1 + L + x_2} = \frac{25}{760 + 220 + 360} = 0.0184 \]

\[ Q_s = \frac{1472 \times 1.00 \times 10^{-6} \times 25 \times 100}{760 + 220 + 360} = 270 \text{ gpm} / 100 \text{ ft}^2 \text{ of levee} \]
Hand Computations used for Verification

Cross Section No. 4 by Rüe

Date 5/23/45
Page 3 of 18
Rev 5/6/47

Beam analysis: Imperious beam

\[ X_L = x_3 \left( \frac{H}{h_a} - 1 \right) - 5 \]

where \( h_a = \frac{h_b}{2} \) and \( x = \frac{X}{L} \)

\[ X_L = 360 \left( \frac{x_3}{4.8} - 1 \right) - 1000 \]

\[ = 316 \text{ ft} \quad 150 \leq X_L \leq 400 \]

\[ X_L = 400 \text{ ft} \]

\[ \text{trial } x = \left( \frac{h_o - h_a}{1 + h_o} \right) 1.25 \]

where \( h_o = 0.82 + (1 - 0.82) \left( \frac{K_{max}}{5 + K_{max}} \right) \)

because \( X_L \) shorted to \( K_{max} \)

\[ h_o = 0.82(4) + (25 - 0.82(4)) \left( \frac{400}{1000 + 400} \right) \]

\[ = 10.6 \text{ ft} \]

\[ \text{trial } x = 1.25 \left( \frac{10.6 - 0.3 \times 4}{1 + 0.3} \right) = 8.4 \text{ ft} \]

Test for beam slope \( m_e = \frac{X - 2}{X - 3} = \frac{8.4 - 2}{400 - 8} = 0.017 < 0.02 \Rightarrow \text{ beam safe} \)

\( x \) must be increased \( x = x_{min} + \left( \frac{X_e - 8}{1.25} \right) + 2 \]

\[ = 0.02(400 - 8) + 2 = 9.8 \text{ ft} \]

\[ V_{vl} = \left[ \delta + \left( \frac{K + K_2}{2} \right) (X_e - 8) + \frac{X_L}{2(m_e - m_e)} \right] \frac{100}{27} \]

\[ = \left[ \delta + \left( \frac{9.8 + 2}{2} \right) (400 - 8) + \frac{9.8}{2(0.5 - 0.02)} \right] \frac{100}{27} \]

\[ = 9370 \text{ yd}^3 / 100 \text{ ft} \]

Cost for imperious beam:

\[ \text{Cost} = V_{vl} \times \text{unit cost} \]

\[ = 9370 \times 1.30 = \$12,200 \text{ per 100 ft of levee station} \]
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 4 by RWC

Date 8/23/65
Page 4 of 18
Rev 5/4/67

Beau analysis: Semi pervious berm

\[
\bar{X}_{sp} = \frac{-A + [A^2 - 24(2 + \lambda)(1 + 5 \cos \phi - \frac{H}{h_0})]^2}{2 \cos \phi (2 + \lambda)}
\]

where

\[ A = 6 + 5 \cos \phi (\lambda + 1) \]

\[ \lambda = \frac{h_0}{h_1} = 0.3 \quad 0.8 = 0.375 \]

\[ A = 6 + 5(1000)(0.002234)(0.375 + 1) \]

\[ = 15.22 \]

\[
\bar{X}_{sp} = \frac{-15.22 + [15.22^2 - 24(2 + 0.375)(1 + [1000 \cos \phi - \frac{25}{4.8}])]^2}{2 \cos \phi (2 + 0.375)}
\]

\[ = 3.14 \text{ ft} \]

Trial \( \lambda = 1.25 \left( \frac{h_0 - \lambda_0 \bar{X}_{sp}}{1 + \lambda_0} \right) \]

where

\[ h_0' = h_0 \left[ 1 + \cos \phi \bar{X}_{sp} + \left( \frac{\lambda + 1}{\lambda_0} \right) \right] \left( \cos \phi \bar{X}_{sp} \right)^2 \]

\[ h_0' = 4.8 \left[ 1 + (0.002234)(3.14) + \left( \frac{2 + 0.375}{0.3} \right) \left( 0.002234 \right)^2 \right] \]

\[ = 9.1 \text{ ft} \]

Trial \( \lambda = 2.25 \left( \frac{9.1 - 0.3 \bar{X}_{sp}}{1 + 0.3} \right) = 7.04 \text{ ft} \)

Test for berm slope \( m_c = \frac{\bar{X}_{sp} - 8}{3.14 - 8} = 0.016 \times 0.02 \quad \text{too small} \)

\( \lambda \) must be increased \( \lambda = \min \left( \frac{\bar{X}_{sp} - 8}{3.14 - 8} + 2 = 8.1 \text{ ft} \)

\[
V_B = \left[ 8 + \left( \frac{\lambda + 1}{\lambda} \right) \left( \bar{X}_{sp} - 8 \right) + \frac{\lambda^2}{2 \left( m_c - m_c \right)} \right] \frac{100}{76}
\]

\[ = \left[ 8 + \left( \frac{8.1 + 1}{8.1} \right)(3.14 - 8) + \frac{8.1^2}{2 (0.35 - 0.03)} \right] \frac{100}{76} \]

\[ = 0.250 \text{ yd}^3 / 100 \text{ ft} \text{ of levee station} \]

Cost for semi pervious berm

\[ \text{Cost} = V_B \times \text{unit cost} = 0.250 \times 1.32 \times \frac{160}{100 \text{ ft levee station}} \]

E97.
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 4 by RWC

Bern analysis: Previous berm with collector

\[
\bar{X}_p = \frac{x_3 \ln \frac{h_0'}{h_a}}{k_t}
\]

where \( h_0' = h_o = \frac{H(x_3)}{x_1 + x_2 + x_3} \)

\[
= \frac{25 (360)}{750 + 220 + 360} = 6.64 \text{ ft}
\]

\( h_a = k_t x_3 = 0.8 \times 6 = 4.8 \text{ ft} \)

\[
\bar{X}_p = 360 \ln \frac{6.6}{4.8}
\]

\[= 114 \text{ ft, but } 150 \leq \bar{X} \leq 400 \]

\(
\therefore \bar{X}_p = 150 \text{ ft}
\)

\[
t_{\text{true}} = \frac{(h_0' - k_t \bar{x}_p^2)}{k_t} 1.25 = 1.25 \left( \frac{6.6 - 0.2 \times 6}{1 + 0.3} \right) = 4.6 \text{ ft}
\]

\[
t_{\text{min}} = 5 \text{ ft on } \bar{X}_{\text{min}} (\bar{X} - 2/\bar{X}) + 2 \text{ ft greater}
\]

\[
= 0.08 (150 - 2/150) + 2 = 4.8 \text{ ft} < t_{\text{min}} = 5 \text{ ft}
\]

\(
\therefore \bar{x} = 5.0 \text{ ft}
\)

\[
V_b = \left[ \delta + \left( \frac{4.12}{2} \right) (\bar{X}_p - \bar{x}) + \frac{4.2}{2 (0.25 + 0.02)} \right] \left( \frac{0.2}{2} \right)
\]

\[
= \left[ \delta + \left( \frac{5.0 - 2}{2} \right) (150 - 5) + \frac{5.0 - 2}{2 (0.25 - 0.02)} \right] \left( \frac{0.2}{2} \right)
\]

\[
= 2070 \text{ yd}^3 / \text{100 ft of levee station}
\]

Note: No cost estimate is made for previous berm since there has been no recent construction experience.
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 4 by Duc

Date 8/27/84
Page 6 of 18
Rev 5/6/87

Beem analysis: Same beem

\[ \bar{z}_s = \frac{1}{3} \left( \bar{z}_p + 2 \bar{z}_{5p} \right) \]

\[ = \frac{1}{3} \left[ 150 + (2)(314) \right] = 259 \text{ ft} \]

Trial \( z = 1.25 \left( \frac{h_0 - 0.282}{1 + a} \right) \)

where \( h_0 = h_o \left[ 1 + e_o (\bar{z}_s + \frac{(2 + a)}{6})(e_o \bar{z}_s)^2 \right] \)

\[ = 4.8 \left[ 1 + (0.03234)(259) + \frac{2.315}{6} \right] \]

\[ = 8.2 \text{ ft} \]

Trial \( z = 1.25 \left( \frac{0.2 - 0.3}{1 + 0.3} \right) = 0.2 \text{ ft} \)

Check \( m = \frac{x - 2}{\bar{z}_s - 8} = \frac{6.2 - 2}{259 - 8} \)

must be increased \( = m_{\text{min}} \left( \bar{z}_s - 8 \right) + 2 \)

\[ = 0.02 \left( 259 - 8 \right) + 2 = 7.0 \text{ ft} \]

\[ V_B = \left[ \frac{8 + \left( \frac{x + 2}{2} \right)}{2 (m - m_{\text{min}})} \right] ^{100} \]

\[ = \left[ \frac{8 + \left( \frac{7.0 + 2}{2} \right)}{2(0.25 - 0.02)} \right] ^{100} \]

\[ = 4610 \text{ yd}^3 / 100 \text{ ft} = 4610 \text{ yd}^3 / 100 \text{ ft} \text{ levee station} \]

Cost for Sand Beem

\[ \text{Cost} = V_B \times \text{unit cost} \]

\[ = 4610 \times 3.75 \approx 17,300 / 100 \text{ ft levee station} \]
**Riverside blanket analysis**

No borrow pit; choose to reinforce existing riverside top stratum, and extend.

\[ x_n = x_2 \left( \frac{H}{k_a} - 1 \right) - L_2 \]

where \( k_a = 0.716 \times 4.2 \text{ ft} \)

\[ = 360 \left( \frac{25}{4.2} - 1 \right) - 220 \]

\[ = 1562 \text{ ft} \]

Input \( L_3 = 2200 \text{ ft} \)

By trial and error determine \( k_{Bb} \) from blanket formula below for open entrance condition:

\[ x_n = \frac{\text{tan}h \ k_{Bb} \ L_3}{k_{Bb}} \]

\[ 1562 = \frac{\text{tan}h \ k_{Bb} (2200)}{k_{Bb}} \]

<table>
<thead>
<tr>
<th>Trial ( k_{Bb} )</th>
<th>( x_2\ k_{Bb} )</th>
<th>( k_{Bb} \ L_3 )</th>
<th>( \frac{\text{tan}h \ k_{Bb} \ L_3}{k_{Bb}} )</th>
<th>( x_n \ k_{Bb} - \frac{\text{tan}h \ k_{Bb} \ L_3}{k_{Bb}} )</th>
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</table>

Use \( k_{Bb} = 0.800524 \)

Using blanket formula for infinite riverside top stratum

\[ z_{Bb} = \frac{1}{k_{Bb} \ k_B} \]

Since \( z_{Bb} = 6 \) and \( z_{Bb} = z_{bn} + z_B \), input \( z_B = 6 \)

\[ 2B_B = 12 \]

\[ k_{Bb} = z_{Bb} \left( \frac{k_B^{-1} k_B}{k_B} \right) \]

\[ = 12 \left[ (0.000524)^{-1} \times 1000 \times 10^{-4} \times 100 \right] \]

\[ = 0.23 \times 10^{-4} \text{ cm/sec} \]

Since \( \frac{z_{Bb}}{k_{Bb}} = \frac{z_{Bn}}{k_{Bn}} + \frac{z_B}{k_B} \)

E100
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 4 by RWC

Date 8/21/69
Page 8 of 18

Riverside blanket analysis (cont')

\[
\begin{align*}
B &= \frac{Z_B}{2B - \frac{Z_B}{2B}} = \frac{6}{12 - 6} \times \frac{1}{0.111 \times 10^{-4} - 0.5 \times 10^{-4}} \\
&= 0.25 \times 10^{-4} \text{ ft}
\end{align*}
\]

\[
V_{RB} = \left[ L_B \times Z_B \right]^{1/3} = \left[ 2200 \times 6 \right]^{1/3} = 48,900 \text{ yd}^3 / 100 \text{ ft of levee station}
\]

With riverside blanket

\[
\begin{align*}
X_1 &= \tan \frac{C_{RB} - B}{C_{RB}} = \tan \left( 0.000524 \right) \left( 2200 \right) \\
&= 0.000524 \\
&= 1.562 \text{ ft}
\end{align*}
\]

\[
X_2 = \tan \frac{C_{RB} - B}{C_{RB}} = \tan \left( 0.000216 \right) \left( 500 \right) \\
&= 0.002236 \\
&= 3.60 \text{ ft}
\]

\[
M = \frac{11}{X_1 + 2X_2 + X_3} = \frac{25}{1562 + 2200 + 360} \\
&= 0.00117
\]

\[
\lambda = \frac{h_1'}{x_2} \text{ where } h_1' = \frac{H \times X_2}{X_1 + 2X_2 + X_3} = \frac{25 \times 360}{1562 + 2200 + 360} = 4.2 \text{ ft}
\]

\[
\lambda = \frac{4.2}{6} = 0.7
\]

\[
Q_6 = \frac{1472 \times L_5 \times D}{X_1 + 2X_2 + X_3} = \frac{1472 \times 0.1 \times 100 \times 25}{1562 + 2200 + 360} \\
&= 1729 \text{ cfm / 100 ft of levee station}
\]

Cost for riverside blanket = \$V_{RB} \times \text{unit cost} = 48,900 \times \$1.20 \\
= \$58,700 / 100 \text{ ft levee station}
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 4 by WCS/KWC

Cutoff Analysis

\[ \chi_1 = 780 \text{ ft} \; ; \; \chi_2 = 360 \text{ ft} \; ; \; L = 220 \text{ ft} \; ; \; D = 100 \text{ ft} \]

\[ \bar{c}_L = \frac{L_L}{L} \; ; \; \Phi_3 = \frac{L_L}{2 \Phi_m} = 1472 \times 10^{-4} \times 0.65 = \frac{q \text{ pm}}{100 \text{ ft}} \]

\[ \Phi_{\ell} = \frac{X_1}{D} = 7.8 \]

\[ \Phi_3 = \ln \left( \frac{1}{1 - \frac{d_c}{D}} \right) + \frac{L_L}{D} - \frac{d_c}{D} = \ln \left( \frac{1}{1 - \frac{d_c}{D}} \right) + 2.2 - \frac{d_c}{D} \]

\[ \Phi_4 = \ln \left( \frac{1}{1 - \frac{d_c}{D}} \right) + \frac{X_2}{D} - \frac{d_c}{D} = \ln \left( \frac{1}{1 - \frac{d_c}{D}} \right) + 3.6 - \frac{d_c}{D} \]

\begin{tabular}{|c|c|c|c|c|c|}
\hline
\( \frac{d_c}{D} \) & \( \Phi_{\ell} \) & \( \Phi_3 \) & \( \Phi_4 \) & \( \frac{q \text{ pm}}{100 \text{ ft}} \) & \( Q_5 \) \\
\hline
0.5 & 7.8 & 2.393 & 3.793 & 13.945 & 263 \text{ qpm/100 ft levee station} \\
0.6 & 7.8 & 2.514 & 3.916 & 14.232 & 258 \\
0.7 & 7.8 & 2.704 & 4.104 & 14.608 & 252 \\
0.8 & 7.8 & 3.009 & 4.409 & 15.218 & 242 \\
0.9 & 7.8 & 3.602 & 5.002 & 16.404 & 224 \\
0.95 & 7.8 & 4.246 & 5.646 & 17.692 & 208 \\
\hline
\end{tabular}

Equations for head:

\[ h_A = H \left( 1 - \frac{\Phi_{\ell}}{2 \Phi_m} \right) = 25 \left( 1 - \frac{7.8}{2 \Phi_m} \right) \]

\[ h_B = h_A - \frac{L_B}{L} (h_A - h_C) \]

\[ h_C = H \left( 1 - \frac{d_c + \Phi_3}{2 \Phi_m} \right) \]

\[ h_D = h_C \left( 1 - \frac{d_c}{d_c + \chi_3} \right) \]

\[ M = \frac{h_A - h_B}{L_2} = \frac{h_A - h_B}{220} \; ; \; \lambda = \frac{h_D}{\chi_3} = \frac{h_D}{L} \]
### Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 4 by WES / RWE

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**Cutoff analysis (cont.)**

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<th>$h_A - h_c$</th>
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<th>$h_D$</th>
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---

**Cost for cutoff, $d_e/0 = 0.95$**

$$d_c + e = 0.95 \times 100 + 6 = 101\text{ ft}$$

Area $E_{2.03} = 65 \times 100 = 6500\text{ ft}^2$

Cost $= 6500 \times 5.00 = 32,500$ $\text{dollars}$

Area $E_{10.1} = (101 - 65) \times 100 = 3600\text{ ft}^2$

Cost $= 3600 \times 5.00 = 18,000$ $\text{dollars}$

**Total cutoff cost** $= \frac{40,500}{101\text{ ft}}$

---

E103
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 4 by Rule

Date 5/24/86
Page 11 of 16

Previous top stratum open exit

Relief well analysis

![Diagram of relief well analysis]

\[ H = 2.5 \text{ ft} \]
\[ D = 100 \text{ ft} \]
\[ \frac{Q_f}{1000} = 1000 \times 10^{-3} \text{ m}^3/\text{sec} \]
\[ x_1 = 75 \text{ ft} \]
\[ x_2 = 6 \text{ ft} \]
\[ L_1 = 220 \text{ ft} \]
\[ x_3 = 360 \text{ ft} \]
\[ F.S. = 1.5 \]
\[ \kappa_a = 0.8 \]
\[ \lambda_0 = 0.57 \]

\[ P < 0.25 \]

\[ a) \quad h_e = \lambda_0 \times x_2 = 0.53(4) = 2.18 \]
\[ b) \quad H_w = h_e = 3.18 \]
\[ \frac{q}{M} = \frac{H - H_w}{x_3} = \frac{2.5 - 3.18}{360} = \frac{3.18}{360} \]
\[ c) \quad \text{Assume } q = 100 \text{ ft}^3/\text{sec} \]
\[ Q_w = 14.72 \times 100 \times \frac{h_e}{D} = 2.012 \text{ ft}^3/\text{sec} \]
\[ d) \quad H_w = 0.57 \text{ ft} \quad \text{from fig. 61} \]
\[ e) \quad h_w = H_w - H_w = 3.18 - 0.57 = 2.62 \text{ ft} \]
\[ f) \quad \Theta_w = \frac{h_w}{Q_w} = 2.62 / (0.01299) = \frac{201.7}{a} \]

\[
\begin{array}{cccc}
q/100 & a & Q_w/100 & \Theta_w \\
75 & 75 & 1.33 & 1.34 \\
100 & 100 & 1.20 & 1.55 \\
125 & 125 & 0.80 & 1.57 \\
\end{array}
\]

\[ g) \quad \text{From fig. 60} \]

\[ h) \quad \text{By inspection } \Theta_w = 1.86 \]

E104
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 4 by R.H.

Date 8/27/86
Page 12 of 16

Relief water analysis (cm³)

1. By interpolation \( a = 100 + 25(0.25) = 110 \) ft
   1st trial wall spacing = 110 ft

2. \( \Theta_{w} \) from fig. 60, \( a_{w} = 110, \ D/a = 0.91 \)
   \( \Theta_{w} = 1.83 \)

\( \theta_{w} = 1.86 > \Theta_{w} = 1.83 \) : Repeat steps c) to h)

3. \( Q_{w} = 14.72 \times a \times D \times 0 = 14.72(110)(0.0125)(0.1)(100) = 210.9 \) ppm

4. \( h_{w} = 0.01 \) ft from fig. 61

5. \( h_{w} = h_{w} - h_{w} = 3.18 - 0.01 = 2.57 \) ft

6. \( \Theta_{w} = h_{w}/a_{w} = \frac{2.57}{a}(0.0125) = \frac{190.8}{a} \)

7. \( a \quad \Theta_{w} \)
   \( 90 \quad 2.20 \)
   \( 100 \quad 1.98 \)
   \( 110 \quad 1.86 \)

8. \( \Theta_{w} \) from fig. 60
   \( \frac{a}{a_{w}} \quad \frac{D}{a} \quad \Theta_{w} \)
   \( 90 \quad 90 \quad 1.11 \quad 1.84 \)
   \( 100 \quad 100 \quad 1.00 \quad 1.65 \)
   \( 110 \quad 110 \quad 0.91 \quad 1.36 \)

9. By inspection \( \Theta_{w} = 1.86 \)

\( \Theta_{w} \) from fig. 60

By interpolation \( a = 100 + 10(0.125) = 107.5 \) ft

Compare \( a = 107 \) with 1st trial \( a = 110 \) – close enough

Use \( a_{w} = 107.5 \) ft

\( Q_{w} = 14.72 \times a \times D \times 0 \)
\( = 14.72(107)(0.0125)(0.1)(100) = 204.9 \) ppm

\( \bar{w} = p \times 0.25(100) = 25 \) ft

E105
Levee Undersea Page Computer Program

Hand Computations used for Verification
Cross Section No. 14 by RWC

Relief well analysis (cm')

P = 0.25 (cm')

Cost per well (for plastic pipe and screen)

\[ CW = (DRT + RP) e_1 + (DRP + WS + PL) \frac{e_1}{w} + S + T + WC + WD \]

\[ = (20 + 30) e_1 + (10 + 25 + 12) (25) + 400 + 300 + 1000 \]

\[ = 64825 \]

Cost per 100% of levee station

\[ CW \% = CW (100/100 \%) = 4825 (100/100) = 4509/100 ft \]

P = 0.375

c) Assume \( a = 125 \) ft; \( Q_a = 14.72 \) ft \( A_k \) / ft

\[ = 14.72 (125) (0.01299) (0.1) (100) = 2399.9 \] ft

d) \( \Delta w = 0.45 \) ft, from fig. 6.1

e) \( \Delta w = \frac{1}{\Delta n} = 3.18 - 0.45 = 2.73 \)

f) \( \Theta w = \Delta \frac{w}{A \Sigma w} = 2.53 \times 0.01299 = \frac{19.5}{\gamma} \)

<table>
<thead>
<tr>
<th>( A_n )</th>
<th>( \Theta w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>1.32</td>
</tr>
<tr>
<td>150</td>
<td>1.30</td>
</tr>
<tr>
<td>100</td>
<td>1.22</td>
</tr>
</tbody>
</table>

\( \Theta w \) from fig. 6.6

\( \frac{a}{\Delta n} \) \( \Delta l \) \( \Sigma \frac{a}{\Delta n} \) \( \Theta w \)

| 125     | 125     | 0.80 | 1.24 |
| 150     | 150     | 0.67 | 1.25 |
| 100     | 100     | 0.62 | 1.26 |

h) By inspection \( \Theta w = 1.24 \)

By interpolation, 1st trial well spacing, \( a_n = 150 + 10 (\frac{4}{6}) \)

\[ = 155 \] ft

d) \( \Theta w \) from fig. 6.6

\( a_n = 155 \), \( \Delta l = 0.45 \); \( \Theta w = 1.36 \)

f) \( \Theta w = 1.24 - \times 1.36 = \) Proceed with steps h) then m)
Relief well analysis (cont.)

2) \[ H_w = h_w = 3.18 \text{ ft} \]
   \[ Q_w = 14.72 \times A_M \times 0.1 \]
   \[ = 14.72 \times (1.55) \times (0.0129) \times (0.1) \times 100 = 296 \text{ gpm} \]

3) \[ H_w = 0.73 \text{ ft from fig. 6} \]

4) \[ h_m = H_m - H_w = 3.18 - 0.73 = 2.45 \text{ ft} \]

5) \[ h_w = h_m \frac{\Theta_w}{\Theta_m} = 2.45 \times \left( \frac{1.26}{1.36} \right) = 2.27 \text{ ft} \]

6) \[ H_w = h_w + H_w = 2.27 + 0.73 = 3.00 \text{ ft} \]

7) \[ A_M = \frac{h - H_w}{x} = \frac{25 - 3.00}{1000} = 0.02 \text{ ft} \]

8) \[ \Theta_m = h_m / A_M = 2.45 / (0.02) = \frac{179.2}{a} \]

9) \[ \Theta_w = \frac{\Theta_m}{a} \]

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \Theta_m )</th>
<th>( \Theta_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>1.30</td>
<td>1.30</td>
</tr>
<tr>
<td>140</td>
<td>1.28</td>
<td>1.25</td>
</tr>
<tr>
<td>150</td>
<td>1.25</td>
<td>1.19</td>
</tr>
</tbody>
</table>

5) By inspection \( \Theta_w = 1.28 \)

By interpolation 2nd trial well spacing \( a = 130 + 10 (1.28) = 136 \text{ ft} \)

6) \[ \Theta_w \text{ from fig. 6 with } a = 136 \text{ ft} \]
   \[ \Theta_w = 0.74 \]

7) \[ \text{Reverses steps 2) to 5) using } a = 136 \text{ ft} \]
   \[ \Theta_w = 1.25 \]
   \[ \Theta_m = 1.32 \]

8) \[ H_m = 3.18 \]
   \[ Q_w = 14.72 \times A_M \times 0.1 \]
   \[ = 14.72 \times (1.36) \times (0.0129) \times (0.1) \times 100 = 2600 \text{ gpm} \]

9) \[ H_w = 0.68 \text{ ft from fig. 6} \]

10) \[ h_m = H_m - H_w = 3.18 - 0.68 = 2.50 \text{ ft} \]
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 4 by RKL

Date 6/27/86
Page 16 of 16

Relief well analysis (cm^3)  \( P = 0.375 \text{ (cm}^3 \text{d)} \)

1. \( h_w = h_m \left( \frac{\Theta_w}{\Theta_m} \right) = 2.37 \left( \frac{1.25}{1.32} \right) = 2.37 \text{ ft} \)
2. \( h_w = h_m + h_w = 2.37 + 0.64 = 3.01 \text{ ft} \)
3. \( \Delta M = \frac{h - h_w}{3} = \frac{2.5 - 3.01}{3} = \frac{-0.51}{3} = 0.017 \text{ ft} \)
4. \( \Theta_m = h_m / \Delta M = \frac{0.50}{0.017} \approx 29.41 \text{ feet} \)

\[
\begin{array}{c|c|c|c}
\text{a} & \text{a} & \text{a} & \text{a} \\
130 & 130 & 0.77 & 1.31 \\
140 & 140 & 0.71 & 1.33 \\
150 & 150 & 0.67 & 1.35 \\
\end{array}
\]

5. By inspection \( \Theta_m = 1.33 \)

By interpolation, 2nd trial well spacing \( a_2 = 130 + 10 (0.77) = 139 \text{ ft} \)

Curve gives \( a_2 = 139 \) with \( a_2 = 136 \) — close enough

\( \Delta a = 136 \text{ ft} \)

\( Q_w = 14.72 a_2 \Delta a \frac{h_w}{D} \)

\( = 14.72 (139) (0.01348) (0.1) (100) = 27.6 \text{ gpm} \)

\( \bar{w} = PD = 0.375 (100) = 37.5 \text{ ft} \)

Cost per well (using plastic pipe and screen)

\( C_W = (DRT + RP) a_2 + (DRP + WS + BF) \bar{w} + BF + WC + WD \)

\( = (20 + 30) 6 + (10 + 85 + 12) 37.5 + 400 + 300 + 1000 \)

\( = 6237 \)

Cost per 100 ft levee station

\( C_{WS} = C_W \times 100 \times \frac{1}{a_2} = 6237 \left( \frac{100}{139} \right) = 4487 \text{ per 100 ft} \)
Relief well analysis (cont.)

\[ P = 0.50 \]

e) Assume \( a = 150 \) ft; \( Q_w = 14.72 \times 10^4 \) k/kf

\[ Q_w = 14.72 \left( 150 \right)^2 \left( 0.01299 \right) \left( 0.1 \right) = 287 \text{ gpm} \]

d) \( H_w = 0.71 \) from fig. 61

e) \( h_w = H_w - H_w = 2.18 - 0.71 = 1.47 \) ft

\[ \Theta_w = \frac{h_w}{\alpha} \times 0.01299 = 2.47 / \alpha \times 0.01299 = \frac{190.1}{\alpha} \]

\[ \begin{array}{ccc}
\alpha & \Theta_w \\
150 & 1.27 \\
170 & 1.12 \\
190 & 1.00 \\
\end{array} \]

f) \( \Theta_w \) from fig. 60

\[ \begin{array}{ccc}
\alpha & \Theta_w \\
150 & 0.67 & 0.97 \\
170 & 0.59 & 0.98 \\
190 & 0.53 & 1.00 \\
\end{array} \]

\[ \begin{array}{ccc}
\alpha & \Theta_w \\
150 & 1.00 \\
170 & 1.12 \\
190 & 1.00 \\
\end{array} \]

\[ \Theta_w = 1.00 \; ; \; 1^{st} \text{ trial well spacing } a = 190 \text{ ft} \]

\[ \Theta_w \text{ from fig. 60; } \Theta_w = 190 \; , \; \%	heta = 0.53 \; , \; \Theta_m = 1.12 \]

\[ \Theta_w = 1.00 \times \Theta_m = 1.12 \; ; \; \text{ Proceed with } \Theta_w \text{ (from fig. 60) to } k_w \]

\[ H_m = h_a = 3.14 \; ; \; Q_m = 14.72 \times 10^4 \text{ k/kf} \]

\[ = 14.72 \left( 150 \right)^2 \left( 0.01299 \right) \left( 0.1 \right) = 363 \text{ gpm} \]

\[ H_w = 0.44 \; \text{ from fig. 61} \]

\[ h_m = H_m - H_w = 3.18 - 0.44 = 2.74 \text{ ft} \]

\[ h_m = h_m \left( \Theta_w / \Theta_m \right) = 2.32 \left( 1.00 / 1.12 \right) = 2.07 \text{ ft} \]

\[ H_w = h_m + H_w = 2.07 + 0.86 = 2.93 \text{ ft} \]

\[ \Delta h = \frac{H_w - H_m}{3} = \frac{2.93 - 2.32}{3} = \frac{0.61}{3} = 0.2033 \]

\[ \Theta_m = \frac{h_m / \Delta h}{a} = 2.32 / a \times 0.01393 = \frac{165.5}{a} \]

\[ \begin{array}{ccc}
\alpha & \Theta_m \\
150 & 1.00 \\
170 & 0.97 \\
190 & 0.91 \\
\end{array} \]

\[ \Theta_m \text{ from fig. 60} \]

\[ \begin{array}{ccc}
\alpha & \Theta_m \\
150 & 0.67 & 1.06 \\
170 & 0.59 & 1.09 \\
190 & 0.53 & 1.12 \\
\end{array} \]

E109
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 4 by Z...

Date 8/27/66
Page 17 of 18

Relief well analysis (cm³)   \( P = 0.50 \) (cm²)

1) By inspection \( \Theta m = 1.07 \)
   
   By interpolation, 2nd trial well spacing \( a_2 = 150 + 20 \times \frac{3}{3} = 155 \) ft

2) \( \Theta aw \) from fig. 60, \( a_2w = 155, D/a = 0.45, \Theta aw = 0.97 \)

3) Repeat steps 2) to 3) using \( \Theta aw = 0.97 \)
   \( \Theta aw = 0.97 \)

4) \( H w = 2.15 \) ft; \( Q w = 14.72 \) A.M. (k ft)

5) \( H w = H w = 3.18 - 0.73 = 2.45 \) ft

6) \( k w = H w (\Theta aw / \Theta wm) = 2.45 \times (0.97/1.07) = 2.22 \) ft

7) \( H aw = h w + H w = 2.22 + 0.73 = 2.95 \) ft

8) \( H M = \frac{4H - H aw}{5 - H aw} = \frac{2.25}{3} = 0.75 = 0.13 \) ft

9) \( \Theta a = \frac{H aw / H M}{2.45 / a (0.01366)} = \frac{17.68}{a} \)

10) \( \Theta aw \) from fig. 60

11) By inspection \( \Theta aw = 1.08 \)

12) By interpolation, 3rd trial well spacing \( a_3 = 160 + 10 \times (\frac{3}{3}) \)

13) \( H w = 163, D/a = 0.41, \Theta aw = 0.97 \)
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 4 by RWG

Date 8/27/66
Page 16 of 16

Relief well analysis (cm^2) P = 0.50 (cm^2)

m) Replace steps 4) to 7) using a = 103 ft, θ_m = 0.97, θ_m = 1.08

k) Ψ_m = 3.18 ft; Q_w = 14.72 x 0.04 ft

= 14.72 x 0.1016 x (0.0125) (0.1) x (100) = 312 gpm

l) Ψ_w = 0.76 gpm from fig. 6.1

m) Ψ_m = Ψ_m - Ψ_w = 3.18 - 0.76 = 2.42 ft

n) Ψ_w = Ψ_m (θ_m/θ_m) = 2.42 (0.97/1.08) = 2.17 ft

o) Ψ_w = Ψ_m + Ψ_w = 2.17 + 0.76 = 2.93 ft

p) δ_m = H - Ψ_w = Ψ_w - Ψ_w = 2.93 - 2.93 = 0.01393

q) θ_m = (Ψ_m/δ_m) = 2.42/0.01393 = 173.7 θ_m

r) θ_m from fig. 6.6

<table>
<thead>
<tr>
<th>a/ft</th>
<th>θ_m</th>
<th>D/ft</th>
<th>θ_m</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>150</td>
<td>0.76</td>
<td>1.06</td>
</tr>
<tr>
<td>160</td>
<td>160</td>
<td>0.62</td>
<td>1.08</td>
</tr>
<tr>
<td>170</td>
<td>170</td>
<td>0.59</td>
<td>1.09</td>
</tr>
</tbody>
</table>

s) By inspection θ_m = 1.08; a_y = 160 ft

Compare a_y = 160 with a_y = 163

Q_w = 14.72 x δ_m (28) = 14.72 (100) (0.01393) (100) = 525 gpm

Ψ_w = P D = 0.50 (100) = 50 ft

Cost per well (using plastic pipe and screen)

C_w = (DR + RP) Δ_w + (DR + WS + FL)Ψ_w + FB + WC + WD

= (20 x 0.1) x (10 x 25 + 12) + 4.0 + 3.0 + 0.0 = $7,650

Cost per 100 ft of levee section

C_w = C_w (100/a_y) = $7,650 (100/160) = $47.81 per 100 ft
PROJECT NAME: PROGRAM DEVELOPMENT
STATION: X-SECT. 4

GENERAL CONTROL MEASURE INPUT DATA

LTE = 165 FT
H = 25 FT
LTD = 120 FT RTD = 100 FT
L1 = 980 FT ENTRANCE = OPEN
L3 = 500 FT EXIT = OPEN
D = 100 FT DD = 100 FT
ZBL = 6 FT KBL = 0.0003 CM/S
ZBR = 6 FT KBR = 0.00005 CM/S
ZT = 6 FT KF = 0.1 CM/S
ZL = 6 FT

SUBWT = 50. LB/CU FT

SUPPLEMENTAL CONTROL MEASURE INPUT DATA

BERM

FSB = UNDEFINED IA = 0.7
I0B = 0.3 M3R = 0.25
I1 = 0.8 M4 = 0.25
M1 = 0.25
M3B = 0.25

RIVERSIDE BLANKET

CUTOFF

NO SPECIAL INPUT REQUIRED

FSW = UNDEFINED
IOW = 0.53
RW = 1.0 FT
DP = 0.67 FT
RUFF = 0.0001
VISCOS = 0.0000121 GAL*FT/SEC
J = UNDEFINED %
HEL = 0.33 FT
PROJECT NAME: PROGRAM DEVELOPMENT  
STATION: X-SECT. 4  

LEVEE UNDERSEEPAGE ANALYSIS  
INITIAL CONDITIONS  

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
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<tbody>
<tr>
<td>X1</td>
<td>782.0 FT</td>
</tr>
<tr>
<td>X3</td>
<td>361.0 FT</td>
</tr>
<tr>
<td>M</td>
<td>1.0835E-01</td>
</tr>
<tr>
<td>I</td>
<td>1.103</td>
</tr>
<tr>
<td>QS</td>
<td>270.0 GPM/100 FT</td>
</tr>
<tr>
<td>Ho</td>
<td>6.60 FT</td>
</tr>
<tr>
<td>$</td>
<td>7339E-01</td>
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</table>

Hand Calculations:  

<table>
<thead>
<tr>
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<th>Value</th>
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<tbody>
<tr>
<td>X1</td>
<td>780.0</td>
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<tr>
<td>X3</td>
<td>360.0</td>
</tr>
<tr>
<td>M</td>
<td>0.0184</td>
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<tr>
<td>I</td>
<td>1.10</td>
</tr>
<tr>
<td>QS</td>
<td>270.0</td>
</tr>
<tr>
<td>Ho</td>
<td>6.6</td>
</tr>
<tr>
<td>$</td>
<td>7339E-01</td>
</tr>
</tbody>
</table>
INIT CONDS

X3 = 360.8
X1 = 781.8
M = 0.0183

I = 1.103
Qa = 270.4
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 4

OUTPUT DATA FOR BERM ANALYSIS
-------------------------------
Hand Calculations

IMPERVIOUS BERM

X1 = 782. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED

XI = 400. FT
T = 9.8 FT
VB = 9404. CU YD/100 FT LEVEE STATION

IMPERVIOUS BERM

VB = 9404. CU YD/100 FT LEVEE STATION
UNIT COST = $ 1.30 /CU YD
TOTAL COST = $ 12225.00 /100 FT LEVEE STATION
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 4

OUTPUT DATA FOR BERM ANALYSIS

SEMIPERVIOUS BERM

X1 = 782. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED

XSP = 313. FT
T = 8.1 FT
VB = 6247. CU YD/100 FT LEVEE STATION

BERM COST CALCULATION

SEMIPERVIOUS BERM

VB = 6247. CU YD/100 FT LEVEE STATION
UNIT COST = $ 1.30 /CU YD
TOTAL COST = $ 8120.00 /100 FT LEVEE STATION

Hand Calculations

E116
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 4

OUTPUT DATA FOR BERM ANALYSIS

PERVIOUS BERM WITH COLLECTOR PIPE

\[ X_1 = 782. \text{ FT} \]
\[ X_3 = \text{UNDEFINED} \]
\[ M = \text{UNDEFINED} \]
\[ I = \text{UNDEFINED} \]
\[ Q_s = \text{UNDEFINED} \]

\[ X_P = 150. \text{ FT} \]
\[ T = 5.0 \text{ FT} \]
\[ V_B = 2073. \text{ CU YD/100 FT LEVEE STATION} \]

BERM COST CALCULATION

PERVIOUS BERM WITH COLLECTOR PIPE

\[ V_B = 2073. \text{ CU YD/100 FT LEVEE STATION} \]
\[ \text{UNIT COST} = ? \text{ NO RECENT CONSTRUCTION EXPERIENCE} \]
\[ \text{TOTAL COST} = ? \text{ NO RECENT CONSTRUCTION EXPERIENCE} \]
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 4

OUTPUT DATA FOR BERM ANALYSIS

--- Hand Calculations ---

SAND BERM

$X_1 = 782. \text{ FT}$

$X_3 = \text{UNDEFINED}$

$M = \text{UNDEFINED}$

$I = \text{UNDEFINED}$

$Q_s = \text{UNDEFINED}$

$X_S = 258. \text{ FT}$

$T = 7.0 \text{ FT}$

$V_B = 4600. \text{ CU YD/100 FT LEVEE STATION}$

BERM COST CALCULATION

---

SAND BERM

$V_B = 4600. \text{ CU YD/100 FT LEVEE STATION}$

UNIT COST = $3.75 /\text{CU YD}$

TOTAL COST = $17251.00 /100 \text{ FT LEVEE STATION}$
PROJECT: PROGRAM DEVELOPMENT  
STATION: X-SECT. 4

OUTPUT DATA FOR BLANKET ANALYSIS

Hand Calculations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
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<tbody>
<tr>
<td>X1</td>
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<tr>
<td>X3</td>
<td>361. FT</td>
</tr>
<tr>
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<td>.1164E-01</td>
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<tr>
<td>I</td>
<td>.700</td>
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<tr>
<td>Qs</td>
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</tr>
<tr>
<td>LB</td>
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</tr>
<tr>
<td>KB</td>
<td>.2420E-04 CM/S</td>
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<tr>
<td>ZB</td>
<td>6.0 FT</td>
</tr>
<tr>
<td>KBB</td>
<td>.3261E-04 CM/S</td>
</tr>
<tr>
<td>ZBB</td>
<td>12.0 FT</td>
</tr>
<tr>
<td>VRB</td>
<td>48889. CU YD/100 FT LEVEE STATION</td>
</tr>
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</table>

IF XR OR LB > DISTANCE TO RIVER, SOLUTION INFEASIBLE

BLANKET COST CALCULATION

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRB</td>
<td>48889. CU YD/100 FT LEVEE STATION</td>
</tr>
<tr>
<td>UNIT COST</td>
<td>$1.20 /CU YD</td>
</tr>
<tr>
<td>TOTAL COST</td>
<td>$58666.00 /100 FT OF LEVEE STATION</td>
</tr>
</tbody>
</table>

E120
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 4

OUTPUT DATA FOR CUTOFF ANALYSIS

\[ \begin{align*}
DC/D &= \cdot 950 \\
X1 &= 782. \text{ FT} \\
X3 &= 361. \text{ FT} \\
M &= \cdot 1902E-01 \\
I &= 1.053 \\
Qs &= 208. \text{ GPM/100 FT}
\end{align*} \]

CUTOFF COST CALCULATION

\[ \begin{align*}
\text{DEPTH} &= 101. \text{ FT} \\
\text{COST} &= \$ 48300.00 /100 \text{ FT OF LEVEE STATION}
\end{align*} \]
PROJECT : PROGRAM DEVELOPMENT
STATION : X-SECT. 4

OUTPUT DATA FOR RELIEF WELL ANALYSIS

\[ X_1 = 782. \text{ FT} \]
\[ X_3 = 361. \text{ FT} \]
\[ Q_S = 270. \text{ GAL/100 FT} \]

<table>
<thead>
<tr>
<th>P</th>
<th>ASEL</th>
<th>WBAR</th>
<th>QW</th>
<th>COST</th>
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<td>139</td>
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<tr>
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<td>160</td>
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<td>38</td>
<td>260.</td>
<td>$4513.00</td>
</tr>
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</table>

\[ \text{Hand Calculations} \]
Cross Section 5
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. S by RWU

Section analyzed is from Stovall, MS levee Section A-A
Ska 77/38+00

Handside toe is chosen to be 400 ft landward of center line
at elevation 144.5 to reflect influence of ditch 500 ft landward of it.
Riverside toe is chosen to be 200 ft riverward of center line
at elevation 144.5.
L1 chosen to be 200 ft to reflect existence of small channel filling
between levee and borrow pit.
Borrow pit appears to be 500 ft wide.
L3 chosen to be 400 ft to reflect existence of large channel filling
and seepage exit is assumed blocked.

Transformation for top stratum

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness ft</th>
<th>Transformation Factor</th>
<th>Transformed Thickness ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Clay</td>
<td>11.5</td>
<td>1</td>
<td>11.5</td>
</tr>
<tr>
<td>E2</td>
<td>Sandy silt</td>
<td>2.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E1+E2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E3</td>
<td>Z = 14.0 ft</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Because most impermeable sub-stratum is on top and is clay
Z_a = Z_{E3} = 11.5 ft and Z_{E2} is chosen to be 1.5 x 10^5 cm/sec

Riverside top stratum (from Boring 14)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness ft</th>
<th>Transformation Factor</th>
<th>Transformed Thickness ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Clay</td>
<td>2.0</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>E2</td>
<td>Silty sand</td>
<td>3.5</td>
<td>0</td>
<td>0</td>
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<tr>
<td>E3</td>
<td>Fine sand</td>
<td>2.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E4</td>
<td>Silty sand</td>
<td>2.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>E5</td>
<td>Silty clay</td>
<td>11.5</td>
<td>1</td>
<td>11.5</td>
</tr>
<tr>
<td>E6</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>E7</td>
<td>Z_n = 23.0 ft</td>
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</tr>
<tr>
<td>E8</td>
<td></td>
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</table>

13.5 ft = Z_{E6}
Simplified Stowell, HS section: Initial conditions

H = 29.5 ft   D = 40 ft   $e_e = 2500 \times 10^{-4}$ cm/sec   $e_w = 0.3$
L_1 = 200 ft   Z_b = 13.5 ft   $e_b = 0.2 \times 10^{-4}$   $i_1 = 0.8$
L_2 = 600 ft   Z_b = 11.5 ft   $e_b = 1.5 \times 10^{-4}$   $u = 29.3 \approx 0.076$
L_3 = 400 ft   Z_b = 11.5 ft

Condition same for Case 7, previous riverside and land side in trachan. Seepage entrance open at L_1 = 200 ft, seepage exit blocked at L_3 = 400 ft

$X_1 = \frac{\tanh C_b e L_1}{C_b}$
where
$C_b = \left( \frac{2 e_b}{k_e^2 Z_b D} \right)^{1/2}$
$e_b = \left( \frac{0.2 \times 10^{-4}}{2500 \times 10^{-4} \times 13.5 \times 40} \right)^{1/2}$
$= 0.000385$
$X_1 = \frac{\tanh (0.000385)(200)}{0.000385} = 199.6 \text{ sqy}, 200 \text{ ft}$

$X_3 = \frac{1}{C_b \tanh C_b e L_3}$
where
$C_b = \left( \frac{2 e_b}{k_e^2 Z_b D} \right)^{1/2}$
$e_b = \left( \frac{1.5 \times 10^{-4}}{2500 \times 10^{-4} \times 11.5 \times 40} \right)^{1/2}$
$= 0.001142$
$X_3 = \frac{1}{(0.001142) \tanh (0.001142)(400)} = 20.50 \text{ ft}$
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by P. W. C.

Date 8/27/85
Page 5 of 22
Rev. 5/7/67

Initial conditions (cm^2)

\[ h_0 = \frac{H}{x_1 + x_2 + x_3} = \frac{29.8}{700 + 600 + 2050} = 0.14 \text{ ft} \]

\[ M = \frac{H}{x_1 + x_2 + x_3} = \frac{29.8}{700 + 600 + 2050} = 0.105 \]

\[ i = \frac{h_0}{x_1} = \frac{21.4}{11.5} = 1.8 > 0.8 \therefore h_0 = 0.3 \]

\[ Q_s = \frac{1472}{x_1 + x_2 + x_3} = \frac{1472 \times 2500 \times 10^{-4}}{200 + 600 + 2050} = 154 \text{ gpm/100 ft of levee station} \]

Impervious dam analysis

\[ ar{X} = x_3 \left( \frac{1 - h_0}{h_0} \right) - S \]

where \( h_a = x_1 + x_2 + x_3 > 0.8 \times 11.5 = 9.2 \text{ ft} \)

and \( S = x_1 + x_3 = 200 + 600 = 800 \text{ ft} \)

\[ \bar{X} = 8050 \left( \frac{29.8}{9.2} - 1 \right) = 500 \]

\[ = 3790 \text{ ft but } 150 \text{ ft } \leq \bar{X} \leq 400 \therefore \bar{X} = 400 \text{ ft} \]

Since \( \bar{X} \) is shortened \( \frac{\bar{X}_{\text{max}}}{\text{max}} = 400 \text{ ft} \)

Trial \( t = 1.25 \left( \frac{h_0 - i x_2}{1 + i} \right) \text{ where } h_0' = 0.8(11.5) + 0.8(11.5) \left( \frac{400}{800 + 400} \right) \]

\[ h_0' = 9.2 + 20.6 (0.333) = 16.1 \text{ ft} \]

\[ t = 1.25 \left( \frac{16.1 - 0.3(11.5)}{1 + 0.3} \right) = 12.2 \text{ ft} \]

Check \( m = \frac{t - 2}{\bar{X} - 2 \sqrt{m_0}} = \frac{12.2 - 2}{400 - 2 \sqrt{20}} = 0.026 > 0.02 \therefore \text{ok} \)

Check \( h_p = \frac{m \times t}{m_1 - m} = \frac{0.076 (12.2)}{0.076 - 0.026} = 18.5 < 1 + 29.8 \therefore \text{ok} \)
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by DWG

Date 5/7/77
Page 4 of 12

Berm analysis: Impervious Berm (con'd)

\[ V_B = \left[ \frac{2 \gamma_3 + \frac{(12.2 + 2)}{2} (400 - 2 \gamma_3) + \frac{12.2}{2}}{2(0.076 - 0.024)} \right] \frac{100}{27} \]

\[ = 15500 \text{yd}^3/100 \text{ft levee station} \]

with berm : \( x_1 = 200 \text{ft} \)

\( x_3, \gamma_1, \lambda, \) & \( Q_5 \) are undefined

Cost for Impervious Berm

\[ \text{Cost} = V_B \times \text{unit cost} = 15,500 \times 9.32 \]

\[ = 142,540 \text{ /100 ft levee station} \]

Semipervious Berm

\[ \overline{A}_{sp} = -A + \left[ A^2 - 24(z + n)(1 + 3c_{bh} - \frac{H}{h_a}) \right]^{1/2} \]

\[ = \frac{c_{bh}}{2} (z + n) \]

where \( A = 6 + 3c_{bh}(n+1) \)

\( n = \lambda_0 / \lambda_1 = 0.3/0.8 = 0.375 \)

\( z = x_1 + L_2 = 200 + 600 = 800 \text{ft} \)

\[ c_{bh} = \left( \frac{1.5 \times 10^{-4}}{0.075 \times 10^{-4} \times 11.5 \times 40} \right)^{1/2} \]

\[ = 0.0011 \text{ ft} \]

\( h_a = \lambda_2 \frac{z}{2} = 0.8 \times 11.5 = 9.2 \text{ ft} \)

\[ A = 6 + 3(800)(1.00142)(0.375 + 1) \]

\[ = 9.76 \]

E127
Levee Undeasure Computer Program

Hand Computations used for Verification
Cross Section No. 5 by RWC

Date 5/7/67
Page 5 of 22

Berm analysis: Semi-previous berm (con'd)

\[ \bar{X}_{sp} = \frac{-9.76 + \left[ 9.76 - 2.4 \left( \frac{2 + 0.175}{4 - 7.2} \right) \right]}{2 \left( \frac{2 + 0.175}{2 + 0.175} \right)} \]

= 612 ft but 150 \( \leq \bar{X} \leq 400 \Rightarrow \bar{X}_{sp} = 400 \) ft

Since \( \bar{X}_{sp} \) has been shortened to \( \bar{X}_{max} = 400 \) ft

\[ h'_0 = 0.8 \bar{X} + (H - 0.8 \bar{X}) \left( \frac{\bar{X}_{max}}{\bar{X} + \bar{X}_{max}} \right) \]

= 0.8 (11.5) + (29.8 - 0.8 (11.5)) \( \frac{200}{800 + 200} \)

= 14.1 ft

As per calculations above for impervious berm

\( \bar{X} = 12.2 \) ft

\[ V_B = \frac{15,600 \text{ yd}^3}{100 \text{ ft levee length}} \]

Cost \( \$20,540 \) /100 ft

with berm: \( \bar{X} = 200 \) ft

\( \bar{X}_3, \bar{X}_4, M, E_3, F_2 \) are undefined

Previous berm with collector

\[ \bar{X}_p = \bar{X}_3 \ln \frac{h'_0}{h_a} \]

where \( h'_0 = \frac{H \bar{X}_3}{\bar{X} + \bar{X}_3} = \frac{29.8 (2050)}{800 + 2050} \)

\[ h_a = \bar{X}_3 + = 0.8 (11.5) = 9.2 \] ft

\[ \bar{X}_p = 2050 \ln \frac{21.4}{9.2} = 17.3 \] ft; but 150 \( \leq \bar{X} \leq 400 \Rightarrow \bar{X}_p = 400 \) ft

Since \( \bar{X}_p \) is shortened to \( \bar{X}_{max} = 400 \) ft,

\[ h'_0 \text{ as above} = 16.1 \text{ ft}; \bar{X} = 12.2 \text{ ft}; V_B = \frac{15,600 \text{ yd}^3}{100 \text{ ft}} \]

Cost for previous berm with collector not calculated

Since there has been no recent construct in experience for determining unit cost estimate.

E128
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 5 by RUC

Date 5/7/67

Page 6 of 22

Bern analysis: Sand berm

\[ \bar{X}_s = \frac{1}{3} (\bar{X}_P + 2\bar{X}_S) = \frac{1}{3} (400 + 2(400)) \]

\[ = 400 \text{ ft} \]

Since \( \bar{X}_P \) was shortened to \( \bar{X}_{\text{max}} = 400 \text{ ft} \),

\[ h_0 \text{ as above} = 16.1 \text{ ft}, \quad t = 12.2 \text{ ft}, \quad V_B = 15,300 \text{ yd}^3/100 \text{ ft}, \]

Cost for Sand berm

\[ \text{Cost} = V_B \times \text{unit cost} \]

\[ = 15,300 \text{ yd}^3/100 \text{ ft} \times 3.75/\text{yd}^3 = 59,300/100 \text{ ft levee sta} \]

With berm \( X_i = 200 \text{ ft} \), \( X_3, \lambda, M, \theta, Q_3 \)

are undefined.
Riverside blanket analysis

Borrow pit, \( L_B = 50 \text{ ft} \), top stratum in borrow pit \( z_m = 0 \)
Assume that previous riverside \( L_1 \) becomes part of levee,
\( L_2 = 600 + 200 = 800 \text{ ft} \)

\[
x_r = x_b \left( \frac{H}{h_a} - 1 \right) - L_2 \quad \text{where} \quad h_a = z_m, \quad x_a = 0.7 \times 11.5 = 8.0
\]

\[
x_3 = 2050 \left( \frac{19.8}{8.0} - 1 \right) - 500 = 4790 \text{ ft}
\]

Assuming that top stratum riverward of borrow pit forms a seepage entrance block, use blanket formula below to
determine \( C_B \) by trial and error.

\[
C_B x_r = \frac{1}{\text{Tanh} C_B L_B}
\]

| Assumed \( C_B \) | \( C_B x_r \) | \( C_B L_B \) | \( \frac{1}{\text{Tanh} C_B L_B} \) | \( \frac{1}{\text{Tanh} C_B L_B} \) - \( C_B x_r \) | \( C_B \) \( C_B = \frac{1}{0.000525} (\frac{h_a}{z_m})^{1/2} \)
<table>
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<td>0.420</td>
<td>0.39693</td>
<td>2.51934</td>
<td>-0.0458 close enough</td>
</tr>
</tbody>
</table>

\[
C_B = \frac{1}{0.000525} \left( \frac{H}{z_m} \right)^{1/2}
\]

\[
\frac{h_a}{h_B} = \frac{1}{C_B} \frac{1}{L_B} = \frac{1}{0.000525 \times 25 \times 40} = 362,600
\]

Choose \( h_a \), then calculate \( C_B \)

If compacted clay silt is available, \( \overline{z_s} = 0.1 \times 10^{-4} \text{ cm/sec} \)

\[
\overline{z_s} = 362,600 \times 0.1 \times 10^{-4} = 3.6 \text{ ft}
\]

\[
V_{RIB} = L_B \times \overline{z_s} \left( \frac{100}{27} \right) = 800 \times 3.6 \times \frac{100}{27} = 10,670 \text{yd}^3/100 \text{ ft} \text{ of levee station}
\]
Levee Underseepage Computer Program

Hand Computations used for Verification  
Cross Section No. 5 by R.W.C

Date 5/24/65  
Page 8 of 22

Riverside blanket (con't)

With blanket, calculate \( x_1, x_2, M, i, \) \& \( Q_3 \)

\[ x_1 (\text{blocked entrance at } 400 \text{ ft}) = \frac{1}{c_{A1} \text{ tanh } c_{A1} L_1} \]

where \( c_{A1} = \left( \frac{h_{A1}}{k_A \text{ tanh } h_{A1}} \right)^{\frac{1}{2}} = \frac{0.15 \times 10^{-4}}{2500 \times 10^{-4} \times 3.2 \times 40} \]

\[ = 0.00527 \]

\[ x_1 = \frac{1}{0.00527 \text{ tanh } (0.00527)(400)} = 4.760 \text{ ft} \]

\[ x_2 (\text{blocked exit at } 400 \text{ ft}) = \frac{1}{c_{B2} \text{ tanh } c_{B2} L_2} \]

where \( c_{B2} = \left( \frac{h_{B2}}{k_B \text{ tanh } h_{B2}} \right)^{\frac{1}{2}} = \frac{0.072 \times 10^{-4}}{2500 \times 10^{-4} \times 3.6 \times 40} \]

\[ = 0.001142 \]

\[ x_2 = \frac{1}{0.001142 \text{ tanh } (0.001142)(400)} = 2.050 \text{ ft} \]

\[ M = \frac{H}{x_1 + x_2 + x_3} = \frac{29.8}{4760 + 600 + 2050} = 0.00357 \]

\[ i = \frac{h_0'}{x_2} \text{ where } h_0' = \frac{H x_2}{x_1 + x_2 + x_3} = \frac{29.8(2.050)}{4760 + 600 + 2050} \]

\[ = 0.07 \text{ ft} \]

\[ \lambda = \frac{5.0}{11.5} = 0.7 \]

\[ Q_3 = \frac{1472 \times k_B \times H D}{x_1 + x_2 + x_3} = \frac{1472 \times 2500 \times 10^{-4} \times 29.8 \times 40}{4760 + 600 + 2050} \]

\[ = 57.6 \text{ gpm/100 ft of levee station} \]

Cost of blanket

Costs \( VRB \) \& unit cost = 10,670 \times \frac{1.20}{12.603/100 \text{ ft}} \]

= \$13,400/100 ft

E131
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. \( k \) by VCS/RWC

Date 8/24/75
Page \( \frac{9}{12} \) of 12

Cut off analysis

\[ x_3 \]

\[ L_3 \]

\[ x_1 \]

\[ L_2 \]

\[ x_4 \]

\[ u \]

\[ \text{Equations for form factors} \]

\[ \Phi_k = \frac{x}{D} \cdot \frac{200}{x_o} = 5 \]

\[ \Phi_3 = \ln\left(\frac{1}{1 - \frac{d_e}{D}}\right) + \frac{L_k}{D} \cdot \frac{d_e}{D} = \ln\left(\frac{1}{1 - \frac{d_e}{D}}\right) + 15 - \frac{d_e}{D} \]

\[ \Phi_4 = \ln\left(\frac{1}{1 - \frac{d_e}{Q}}\right) + \frac{x_4}{D} \cdot \frac{d_e}{D} = \ln\left(\frac{1}{1 - \frac{d_e}{D}}\right) + 51.5 - \frac{d_e}{D} \]

\[
\begin{array}{cccccccccc}
\text{dc/d} & \text{dc} & \text{ln(1-d_e/D)} & \Phi_k & \Phi_3 & \Phi_4 & \Sigma \Phi_m & Q_s \\
0.5 & 0.493 & 15.193 & 51.693 & 71.886 & 152.934/102.67 & 48.687 \\
0.6 & 0.916 & 12.316 & 51.816 & 72.132 & 152.496 & 151 & 150 & 148 \\
0.7 & 1.204 & 15.504 & 52.004 & 72.508 & 149 & 150 & 148 \\
0.8 & 1.609 & 15.809 & 52.309 & 73.118 & 148 & 150 & 148 \\
0.9 & 2.303 & 16.403 & 52.903 & 74.706 & 148 & 150 & 148 \\
0.95 & 2.985 & 17.045 & 53.545 & 75.690 & 148 & 150 & 148 \\
\end{array}
\]

E132
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by W.C./R.W.C.

Date 5/15/45
Page 10 of 22

Cutoff analysis (cm')

Equations for head

\[ h_a = H \left(1 - \frac{\Phi_c}{\Phi_m}\right) \]

\[ h_c = H \left(1 - \frac{\Phi_c + \Phi_a}{\Phi_m}\right) \]

\[ h_b = h_a - \frac{L_a}{L_a + L_{dc}} (h_a - h_c) = h_a - \frac{600}{600 + L_{dc}} (h_a - h_c) \]

\[ h_d = h_c \left(1 - \frac{d_{dc}}{d_{dc} + 2s}\right) = h_c \left(1 - \frac{d_{dc}}{200 + L_{dc}}\right) \]

\[ M = \frac{h_a - h_b}{L_a} = \frac{L_{dc}}{600} \]

\[ i = \frac{h_{dc}}{Z_a} = \frac{L_{dc}}{115} \]

<table>
<thead>
<tr>
<th>( \frac{d_{dc}}{} )</th>
<th>( d_{dc} )</th>
<th>( h_a )</th>
<th>( h_c )</th>
<th>( h_a - h_c )</th>
<th>( h_b )</th>
<th>( h_d )</th>
<th>( i )</th>
<th>( M )</th>
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<td>20.98</td>
<td>1.825</td>
<td>0.0103</td>
</tr>
<tr>
<td>0.9</td>
<td>36</td>
<td>27.79</td>
<td>21.22</td>
<td>6.57</td>
<td>21.59</td>
<td>20.88</td>
<td>1.817</td>
<td>0.0103</td>
</tr>
<tr>
<td>0.95</td>
<td>38</td>
<td>27.83</td>
<td>21.11</td>
<td>6.72</td>
<td>21.51</td>
<td>20.78</td>
<td>1.802</td>
<td>0.0105</td>
</tr>
</tbody>
</table>

Cost of cutoff \( \frac{d_{dc}}{} = 0.95 \)

\[ d_{dc} + 2a = 0.95d + 2a = 0.95(4.0) + 14 = 52 \text{ ft} \]

Area \( \frac{3.00}{\text{ft}^2} = 52 \times 100 = 5200 \text{ ft}^2 \)

Cost \( = 5200 \times \frac{3.00}{\text{ft}^2} \times 15 \text{ $/100 ft}$ levee station

E133
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 5 by JKC

Simplified Steevall, HS Section

Relief well analysis

\[ D = \frac{2.5 \times 10^{-4}}{I_{w}} \text{cm/sec} \]
\[ I_{w} = 0.8 \]
\[ F.S. = 1.5 \]
\[ I_{o} = 0.53 \]
\[ h_{w} = 1.4 \]

Determine area for \( P = 0.25 \)

\( h_{w} = I_{o} x_{d} = 0.53 \times 11.5 = 6.10 \text{ ft} \)

b) Assume \( h_{w} = h_{a} = 6.10 \text{ ft} \)

\[ \Delta H = \frac{H - h_{w}}{x_{a}} = \frac{29.8 - 6.10}{200} = 0.08645 \]

c) Assume \( a = 100 \text{ ft} \)

\[ Q_{w} = 14.72 \times \Delta H \times k \times D \]

\[ Q_{w} = 14.72 \times (2.35 \times 0.0065)(0.15)(40) = 392 \text{ qvm} \]

d) \( h_{w} = 0.91 \text{ ft} \) from fig. 61

e) \( h_{w} = h_{w} - h_{w} = 6.10 - 0.91 = 5.19 \text{ ft} \)
Levee Unders sepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by RUC

<table>
<thead>
<tr>
<th>Relief wave analysis (cm²) P = 0.25 (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>f) ( \theta_w = \frac{h_{aw}}{a_{aw}} = \frac{5.19}{a(0.02645)} = \frac{194.7}{a} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>q) from fig. 60 a</th>
<th>( \frac{h_{aw}}{a_{aw}} )</th>
<th>( \frac{h_{aw}}{a_{aw}} )</th>
<th>( \theta_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
<td>0.43</td>
<td>1.92</td>
</tr>
<tr>
<td>125</td>
<td>125</td>
<td>0.34</td>
<td>1.87</td>
</tr>
<tr>
<td>150</td>
<td>150</td>
<td>0.27</td>
<td>1.89</td>
</tr>
</tbody>
</table>

h) By inspection \( \theta_w = 1.48 \)
Interpretation \( a = 125 + 25 (\frac{a}{2a}) = 133 \) ft
1st trial wave spacing = 133 ft

i) \( \theta_m = \frac{h_{aw}}{a_{aw}} = \frac{133}{0.30} = 4.44 \)

j) \( \theta_m = 1.48 < \theta_m = 1.58 \); proceed with steps k) to m)

k) \( h_m = h_a = 6.10 \) ft; \( aM = 0.02645 \) from f)

\( Q_m = 14.72 aM \) ft²

\( = 14.72(133)(0.02645)(0.25)(40) = 5.22 \) ft²

| l) \( h_{aw} = 1.16 \) ft from fig. 61 |

m) \( h_m = h_{aw} + h_{aw} = 6.10 + 1.16 = 4.94 \) ft

h) \( h_a = h_m \left( \frac{\theta_w}{\theta_m} \right) = 4.94 \left( \frac{1.48}{1.58} \right) = 4.63 \) ft

o) \( h_w = h_m + h_{aw} = 4.63 + 1.16 = 5.79 \) ft

p) \( \delta M = \frac{H - \delta H}{s} - \frac{h_{aw}}{h_{aw}} = \frac{29.8 - 5.79}{200} = \frac{5.79}{200} = 0.02719 \)

q) \( \theta_m = \frac{h_{aw}}{aM} = \frac{4.94}{a(0.02719)} = \frac{181.7}{a} \)

<table>
<thead>
<tr>
<th>a</th>
<th>( \theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>1.40</td>
</tr>
<tr>
<td>140</td>
<td>1.30</td>
</tr>
<tr>
<td>150</td>
<td>1.21</td>
</tr>
<tr>
<td>160</td>
<td>1.15</td>
</tr>
<tr>
<td>120</td>
<td>1.51</td>
</tr>
</tbody>
</table>

E135
### Levee Underseepage Computer Program

**Hand Computations used for Verification**

Cross Section No. 5 by RIZLA.

Date 9/1/46

Page 13 of 23

#### Relief Well Analysis (cm^3?)

<table>
<thead>
<tr>
<th>a</th>
<th>Q/a</th>
<th>ΔQ/a</th>
<th>Θm</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>110</td>
<td>0.56</td>
<td>1.54</td>
</tr>
<tr>
<td>120</td>
<td>120</td>
<td>0.33</td>
<td>1.56</td>
</tr>
<tr>
<td>130</td>
<td>130</td>
<td>0.31</td>
<td>1.57</td>
</tr>
</tbody>
</table>

5) By inspection \( Θ_m = 1.55 \)
   - By interpolation \( a = 110 \times 10 (1/14) = 117 \) ft
   - 2nd twice well spacing = 117 ft

6) \( Θ_m \) from fig. 60, \( h_w = 17 \) \( ΔQ/a = 0.34 \) \( Θ_m = 1.45 \)

7) Repeat steps 6) to 5) using \( a = 117 \)
   - \( Θ_m = 1.45 \)
   - \( Θ_m = 1.55 \)

8) \( h_m = h_a = 6.10 \) ft; \( ΔM = 0.02665 \) from b)

   \[ Q_m = 14.72 \times 0.02665 \]
   \[ = 0.398 \text{ ft}^3 \]

9) \( h_w = 1.03 \) ft from fig. 41

10) \( h_m = h_m - h_w = 6.10 - 1.03 = 5.07 \) ft

11) \( h_a = h_m (Θ_m/Θ_a) = 5.07 (1.45/1.55) = 4.74 \) ft

12) \( h_w = h_a + h_w = 4.74 + 1.03 = 5.77 \) ft

13) \[ ΔM = H - H_a = \frac{H_a - H}{\frac{\Theta_m}{\Theta_a}} = \frac{29.8 - 5.77}{\frac{5.07}{1.03}} = 0.02722 \]

14) \[ Θ_m = h_m/ΔM = \frac{5.07}{0.02722} \]

<table>
<thead>
<tr>
<th>a</th>
<th>Q/a</th>
<th>ΔQ/a</th>
<th>Θm</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>110</td>
<td>0.34</td>
<td>1.54</td>
</tr>
<tr>
<td>120</td>
<td>120</td>
<td>0.33</td>
<td>1.56</td>
</tr>
<tr>
<td>130</td>
<td>130</td>
<td>0.31</td>
<td>1.57</td>
</tr>
</tbody>
</table>

E136
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by RWW

Date 9/1/56 Page 14 of 32

Relief well analysis (cm-1)

P = 0.25 (con'd)

2) By inspection \( \Theta_{w} = 1.5 \)

By interpolation \( a = 110 + 10(1/14) = 115.7 \)

Compare 115.7 with minimum well spacing = 117 ft: good enough

\( \Theta_{w} = 115.7 \)

\( Q_{w} = 14.72 \times \alpha \times \text{ft}^{3}/\text{day} \)

= 14.72(1.19)(0.02665)(0.25)(40) = 467 qpm

\( \bar{W} = \frac{P \times D}{0.25(40)} = 1056 \)

Cost per well (for plastic pipe and screen)

\( CW = (DR + RP) \times L + (DR_{p} + WS + FL) \bar{W} + BF + WC + WD \)

= \((20 + 30)\times 14.0 + (16 + 85 + 12)\times 10 + 400 + 300 + 1000 = \$3530 \)

Cost per 100 ft of levee station

\( CW_{S} = CW \left( \frac{100}{\Theta_{w}} \right) = 3530 \left( \frac{100}{119} \right) = \$2970 \text{ per 100 ft} \)

\( P = 0.575 \)

c) Assume \( a = 125 \text{ ft} \) \; \( Q_{w} = 14.72 \times \alpha \times \text{ft}^{3}/\text{day} \)

= 14.72(125)(0.02665)(0.25)(40) = 490 qpm

d) \( h_{w} = 1.10 \text{ ft} \) from fig. 61

e) \( h_{w} = h_{w} - h_{w} = 6.10 - 1.10 = 5.00 \text{ ft} \)

f) \( \Theta_{w} = h_{w}/\alpha \times 44 = 5.00/\alpha (0.02465) = \frac{187.6}{\alpha} \)

\begin{array}{|c|c|c|c|}
\hline
\alpha & \Theta_{w} \\
\hline
125 & 1.50 \\
150 & 1.25 \\
175 & 1.07 \\
\hline
\end{array}

\begin{array}{|c|c|c|c|}
\hline
\Theta_{w} \text{ from fig. 60} & a & \Theta_{w}/a & \% & \Theta_{w} \\
125 & 125 & 1.03 \\
150 & 150 & 1.05 \\
175 & 175 & 1.10 \\
\hline
\end{array}

E137
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by RWC

Date 9/2/84
Page 18 of 22

Relief well analysis (cm4) P = 0.375 (cm4)

h) By inspection \( \Theta_m = 1.00 \)

By extrapolation \( a = 175 + 25 \times \frac{1}{2} = 176 \text{ ft} \)

1st trial well spacing, \( a = 176 \text{ ft} \)

i) \( \Theta_m \) from fig. 6.0; \( a/\mu_0 = 176 \), \( \mu_0 = 0.23 \)

\( \Theta_m = 1.20 \)

j) \( \Theta_m = 1.00 < \Theta_m = 1.20 \); -- Proceed with steps k) to m)

k) \( H_w = H_0 = 6.10 \text{ ft};\) \( \Delta M = 0.02665 \text{ from } h) \)

\( Q_w = 14.72 \times 0.02665 = 0.389 \text{ ft}^3/\text{sec} \)

l) \( H_w = 1.56 \text{ ft} \) from fig. 6.1

m) \( h_m = H_m - H_w = 4.10 - 1.56 = 2.54 \text{ ft} \)

n) \( h_a w = h_m \left( \frac{\Theta_m}{\Theta_m} \right) = 4.52 \times 1.20 = 5.42 \text{ ft} \)

o) \( H_a w = h_a w + H_w = 5.42 + 1.56 = 6.98 \text{ ft} \)

p) \( \Delta M = \frac{H - H_a w - H_a w}{\lambda_1} = \frac{29.4 - 5.57 - 5.57}{5.57} = 0.02757 \)

\( \Theta_m = \frac{h_m}{a \Delta M} = \frac{4.52 \times \left( 0.02757 \right)}{a} = \frac{163.9}{a} \)

\( \begin{array}{cc|c|c|c}
   a & \frac{a}{\mu_0} & \frac{Q_w}{a} & \Theta_m \\
   \hline
   125 & 125 & 0.32 & 1.14 \\
   150 & 150 & 0.27 & 1.17 \\
   175 & 175 & 0.23 & 1.20 \\
\end{array} \)

q) \( \Theta_m = 1.16 \)

By interpolation \( a = 125 + 25 \left( \frac{175}{125} \right) = 142 \text{ ft} \)

2nd trial well spacing, \( a = 142 \text{ ft} \)

E138
Levee Underssepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by Qwu

Date: 7/12/82
Page: 16 of 22

Relief well analysis (cont'd)

1) \( \theta_w \) from Fig 60; \( \frac{a}{h_w} = 14.2 \), \( \theta_w = 1.04 \)

2) Repeat steps 1) to 5) using \( \theta_w = 1.04 \)

3) \( h_m = h_w - h_w = 6.10 - 1.23 = 4.87 \) ft

4) \( h_m = h_m (\theta_w / \theta_m) = 4.87 (1.04/1.16) = 4.37 \) ft

5) \( h_w = h_m + h_w = 4.37 + 1.23 = 5.60 \) ft

6) \( \Delta M = \frac{M - h_w}{5} = \frac{29.8 - 6.60}{5.60} = 0.02742 \)

7) \( \theta_m = \frac{h_m}{a \Delta M} = \frac{4.87/4(0.02742)}{a} = \frac{177.0}{a} \)

\[ \begin{array}{c|c|c|c}
\theta_m & a & \frac{a}{h_w} & \frac{h_w}{a} \\
140 & 140 & 0.35 & 1.14 \\
150 & 150 & 0.27 & 1.17 \\
160 & 160 & 0.25 & 1.18 \\
\end{array} \]

8) By inspection \( \theta_m = 1.17 \)

By interpolation \( a = 150 + 10(1.17 - 1.16) = 151 \) ft

Compare 151 ft with 2nd trial well spacing \( a_2 = 142 \) ft

Repeat steps 4) to 5) using 3rd trial well spacing \( a_3 = 151 \) ft

9) \( \theta_w \) from Fig 60; \( \frac{a}{h_w} = 151 \), \( \theta_w = 1.05 \)

10) Repeat using \( a_3 = 151 \) ft, \( \theta_w = 1.05 \), \( \theta_m = 1.17 \)

E139
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by RWE

Date 9/21/76
Page 17 of 22

Calculation

P = 0.375 (cm²)

Relief well analysis (cm²)

\( P = 0.375 \) (cm²)

1) \( h_m = h_w - 0.50; \Delta M = 0.02605 \) (cm²)

\( Q_w = 14.72 \) a \( \Delta M \) ft

\( z = 14.72 (15) (0.02605) (0.25) (40) = 59.2 \text{ gpm} \)

2) \( h_w = 1.32 \) ft

3) \( h_m = h_m - h_w = 0.10 - 1.32 = 4.78 \) ft

4) \( h_w = h_m (\frac{\theta_m}{\theta_m}) = 4.78 \) (1.05/1.17) = 4.29 ft

5) \( h_w = h_w + h_w = 4.29 + 1.32 = 5.61 \) ft

6) \( \Delta M = \frac{H - H_m}{s} = \frac{29.6 - 5.61}{2050} = \frac{5.61}{2050} = 0.02750 \)

7) \( \theta_m = \frac{h_m / a \Delta M}{s} = \frac{4.78}{a \cdot 0.02750} = \frac{173.8}{a} \)

8) \( \theta_m \) from fig 60

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td>1.40</td>
</tr>
<tr>
<td>150</td>
<td>1.16</td>
</tr>
<tr>
<td>160</td>
<td>1.09</td>
</tr>
</tbody>
</table>

9) By inspection \( \theta_m = 1.17 \)

By interpolation \( a = 140 + 10 (7/8) = 149 \) ft

Compare 149 ft with 3d trial well spacing \( a_3 = 151 \) ft

Good enough \( Q_{set} = \frac{149}{a} \)

\( Q_w = 14.72 \) a \( \Delta M \) ft

\( z = 14.72 (149) (0.02750) (0.25) (40) = 603.9 \text{ gpm} \)

\( \bar{w} = \bar{P} D = 0.375 \) (40) = 15 ft

E140
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. by RWC

P = 0.375 (cu. ft)

Cost per well (using plastic pipe and screen)

\[ CW = (DR_T + RP) \times L + (DR_P + WS + FL)W + BL + WC + WD \]
\[ = (20 + 30) \times 14 \times 1 + (16 + 8 \times 12) \times 15 + 400 + 300 + 100 \]
\[ = \$405 \]

Cost per 100 ft of levee station

\[ cws = CW \times \frac{100}{48} = 405 \times \frac{100}{48} = 875 \]

P = 0.50

a) Assume \( a = 150 \) ft; \( Q_m = 14.72 \) cu. ft

\[ = 1472 \times (0.02665 \times 0.44) = 588.9 \text{ gpm} \]

d) \( H_m = 1.32 \) ft from Fig. 60

e) \( h_v = H_m - H_w = 0.10 \times 1.32 = 0.13 \) ft

f) \( \theta_m = h_v/a \times 100 = 4.7\% \cdot (0.02665) = \frac{179.4}{a} \)

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>0.17</td>
</tr>
<tr>
<td>175</td>
<td>0.13</td>
</tr>
<tr>
<td>200</td>
<td>0.10</td>
</tr>
<tr>
<td>225</td>
<td>0.08</td>
</tr>
</tbody>
</table>

h) By inspection \( \theta_m = 0.87 \)

By interpolation \( a = 200 + 25 (\frac{0.87}{0.84}) = 215 \) ft

1st trial spacing \( a = 215 \) ft

i) \( \theta_m \) from Fig. 60; \( a/\theta_m = 215, \theta_m = 0.19 \). Then \( \theta_m = 1.02 \)

j) \( \theta_m = 0.87 < \theta_m = 1.02 \); proceed with steps (k) to (m)
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by RWC

Date 9/2/66
Page 19 of 22

Relief well analysis (cont.)

P = 0.50 (cont.)

k) \( H_m = h_w = 0.10 \), \( \Delta M = 0.02445 \) from b)

\[ Q_w = 14.72 - \Delta M \times k \times D \]

\[ = 14.72 (0.15)(0.02445)(0.25)(40) = 8.43 \text{ gpm} \]

l) \( H_m = 2.04 \text{ ft} \) from fig. 61

m) \( h_m = H_m - H_w = 0.10 - 2.02 = 4.08 \text{ ft} \)

n) \( h_w = h_m (\Theta m/\Theta n) = 4.08 (0.57/1.02) = 3.48 \text{ ft} \)

o) \( H_n = h_w + H_w = 3.48 + 2.02 = 5.50 \text{ ft} \)

p) \( \Delta M = \frac{H - H_n}{H_n} - \frac{H_w}{H_n} \times \frac{25.4 - 5.50}{5.50} = 0.02709 \)

q) \( \Theta m = \frac{h_m}{\Delta M} = 4.08/0.02709 = \frac{147.3}{a} \)

r) By interpolation \( \Theta m = 0.94 \)

s) \( \Theta m \text{ from fig. 60} \)


t) \( \Theta n \text{ from fig. 60} \), \( a/\Delta n = 152, b/s = 0.26, \text{ then } \Theta n = 0.82 \)

u) Repeat steps k) to t) using \( a_t = 152 \text{ ft} \)

\( \Theta n = 0.82 \)

\( \Theta m = 0.97 \)

v) \( H_t = 6.10; \Delta n = 0.02645 \) from b)

\[ Q_w = 14.72 \times \Delta n \times k \times D \]

\[ = 14.72 (152)(0.02645)(0.25)(40) = 596 \text{ gpm} \]

w) \( H_w = 1.33 \text{ ft} \) from fig. 61

E142
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by RWC

<table>
<thead>
<tr>
<th>Relief well analysis (cont.)</th>
<th>$P = 0.50$ (cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_2$) $h_m = H_m - H_w = 0.10 - 1.33 = 4.77$ ft</td>
<td></td>
</tr>
<tr>
<td>$n_2$) $h_m = h_m (\theta_m/\theta_w) = 4.77 (0.63/0.91) = 3.03$ ft</td>
<td></td>
</tr>
<tr>
<td>$o_2$) $h_w = h_m + H_w = 4.03 + 1.33 = 5.36$ ft</td>
<td></td>
</tr>
<tr>
<td>$p_2$) $\Delta M = \frac{H - H_w}{2} \frac{N_m}{x_3} = 800 \frac{29.8 - 5.36}{2050} = 0.02744$</td>
<td></td>
</tr>
<tr>
<td>$q_2$) $\theta_m = h_m/\Delta M = 4.77/0.02744 = \frac{170.7}{a}$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$r_2$) $\theta_m$ from fig. 60</th>
<th>$a$</th>
<th>$\theta_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>150</td>
<td>0.27</td>
</tr>
<tr>
<td>160</td>
<td>160</td>
<td>0.25</td>
</tr>
<tr>
<td>170</td>
<td>170</td>
<td>0.24</td>
</tr>
<tr>
<td>180</td>
<td>180</td>
<td>0.22</td>
</tr>
</tbody>
</table>

5.2) By inspection $\theta_m = 0.99$

By interpolation $a = 170 + 10 (0.95) = 172$ ft

Compare 172 ft with 2nd trial well spacing $a_t = 152$ ft

Repeat steps $k)$ to $t)$ using 3rd trial well spacing $a_t = 172$ ft

$e_3$) $\theta_m = 0.84, \theta_w = 0.84, \theta_m = 0.99$

$g_3$) $H_m = h_m = 6.10$ ft; $\alpha_m = 0.02665$ $\alpha_m = 1.4$

$Q_w = 14.72 \times \Delta M \times D$

$= 14.72 (172)(0.02665)(0.25)(43) = 675$ q pm

$g_3$) $H_w = 1.55$ ft $\alpha_m = 0.99$

$g_3$) $h_m = H_m - h_w = 6.10 - 1.55 = 4.55$ ft

$g_3$) $h_w = h_m (\theta_m/\theta_w) = 4.55 (0.84/0.99) = 3.96$ ft

$g_3$) $H_w = h_w + H_w = 3.84 + 1.55 = 5.41$ ft

E143
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by RWC

Date 9/1/86  Page 21 of 21

1. Relief well analysis (cm'd) \( P = 0.50 \) (cm'd)

\[ \Delta h = \frac{14 - 12}{5} = \frac{2.8}{5} \]

\[ \Delta w = \frac{29.5 - 5.41}{80} \approx 0.2785 \]

2. \( \theta_m = \frac{\Delta h}{\Delta w} = 4.55/0.02785 = 163.4 \]

3. \( \theta_m \) from fig. 60

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>1.02</td>
</tr>
<tr>
<td>160</td>
<td>1.02</td>
</tr>
<tr>
<td>170</td>
<td>0.96</td>
</tr>
</tbody>
</table>

4. By interpolation \( \theta_m = 1.02 - 4(0.97) = 0.977 \)

5. By interpolation \( a = 160 + 10(43/60) = 167 \) ft

Compare 167 ft with 3rd trial well spacing \( a_3 = 172 \) ft

Good enough \( a_{sel} = 167 \) ft

\[ Q_m = 14.72 \Delta \theta w \]

\[ w = P D = 0.50(40) = 20 \text{ ft} \]

Cost per well (using plastic pipe and screen)

\[ C_W = (DR + RP) 2 \ell + (DRP + W + FL) \overline{w} + BF + WC + UD \]

\[ = (20 + 20) 14.0 + (16 + 85 + 12) 20 + 400 + 300 + 1000 \]

\[ = \$ 4660 \]

Cost per 100 ft of levee station

\[ C_{WS} = C_W (100/a_{sel}) = 4660 \times \frac{100}{167} = \$ 2790 \text{ per 100 ft} \]
Cost Summary all Control Measures

Impervious berm:
Volume = 15,500 yd³/100 ft levee station
Unit cost = $1.50/yd³
Total cost = $23,250/100 ft levee station

Semi-pervious berm
Volume = 15,500 yd³/100 ft levee station
Unit cost = $1.50/yd³
Total cost = $23,250/100 ft levee station

Pervious berm with collector pipe
Volume = 15,500 yd³/100 ft levee station
Unit cost = not estimated
Total cost = not calculated

Sand berm
Volume = 15,500 yd³/100 ft levee station
Unit cost = not estimated
Total cost = not calculated

Riverside blanket
Volume = 10,700 yd³/100 ft levee station
Unit cost = $1.20
Total cost = $12,840/100 ft levee station

Cut off - dc/a = 0.95
Depth = 52 ft
Total cost = $15,600/100 ft levee station

Relief well - lowest cost
Depth = 52 ft
Spacing = 149 ft
Total cost = $2750/100 ft levee station
PROJECT NAME: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

GENERAL CONTROL MEASURE INPUT DATA

\[\begin{align*}
\text{LTE} & = 164.5 \text{ FT} \\
\text{H} & = 29.8 \text{ FT} \\
\text{LT0} & = 400 \text{ FT} \quad \text{RTO} = 200 \text{ FT} \\
\text{L1} & = 200 \text{ FT} \quad \text{ENTRANCE} = \text{OPEN} \\
\text{L3} & = 400 \text{ FT} \quad \text{EXIT} = \text{BLOCKED} \\
\text{D} & = 40 \text{ FT} \quad \text{DD} = 40 \text{ FT} \\
\text{ZBL} & = 11.5 \text{ FT} \quad \text{KBL} = 0.00015 \text{ CM/S} \\
\text{ZBR} & = 13.5 \text{ FT} \quad \text{KBR} = 0.00002 \text{ CM/S} \\
\text{ZT} & = 11.5 \text{ FT} \quad \text{KF} = 0.25 \text{ CM/S} \\
\text{ZL} & = 14 \text{ FT} \\
\text{SUBWT} & = 50. \text{ LB/CU FT}
\end{align*}\]

SUPPLEMENTAL CONTROL MEASURE INPUT DATA

\[\begin{align*}
\text{FSB} & = \text{UNDEFINED} \\
\text{I0B} & = 0.3 \\
\text{I1} & = 0.8 \\
\text{M1} & = 0.076 \\
\text{M3B} & = 0.25 \\
\text{IA} & = 0.7 \\
\text{M3R} & = 0.25 \\
\text{M4} & = 0.19
\end{align*}\]

CUTOFF

\[\begin{align*}
\text{FSW} & = \text{UNDEFINED} \\
\text{IOW} & = 0.53 \\
\text{RW} & = 1.0 \text{ FT} \\
\text{DP} & = 0.67 \text{ FT} \\
\text{RUFS} & = 0.00001 \\
\text{VISCOS} & = 0.0000121 \text{ GAL*FT/SEC} \\
\text{J} & = \text{UNDEFINED} \% \\
\text{HEL} & = 0.33 \text{ FT}
\end{align*}\]
PROJECT NAME: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

LEVEE UNDERSEEPAGE ANALYSIS
INITIAL CONDITIONS

\[
\begin{align*}
X_1 &= 200. \text{ FT} \\
X_3 &= 2048. \text{ FT} \\
M &= 0.1046E-01 \\
I &= 1.864 \\
Q_S &= 154. \text{ GPM/100 FT} \\
H_0 &= 21.4 \text{ FT} \\
* &= 0.1405E-01
\end{align*}
\]
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

OUTPUT DATA FOR BERM ANALYSIS

IMPERVIOUS BERM

X1 = 200. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED

XI = 400. FT
T = 12.1 FT
VB = 15726. CU YD/100 FT LEVEE STATION

BERM COST CALCULATION

IMPERVIOUS BERM

VB = 15726. CU YD/100 FT LEVEE STATION
UNIT COST = $ 1.30 /CU YD
TOTAL COST = $ 20443.00 /100 FT LEVEE STATION

E149
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

OUTPUT DATA FOR BERM ANALYSIS
-------------------------------------

SEMIPERVIOUS BERM

Hand Calculations

X1 = 200. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED

XSP = 400. FT
T = 12.1 FT
VB = 15726. CU YD/100 FT LEVEE STATION

BERM COST CALCULATION
-------------------------------

SEMIPERVIOUS BERM

VB = 15726. CU YD/100 FT LEVEE STATION
UNIT COST = $ 1.30 /CU YD
TOTAL COST = $ 20443.00 /100 FT LEVEE STATION

E150
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

OUTPUT DATA FOR BERM ANALYSIS

PERVIOUS BERM WITH COLLECTOR PIPE

\[ X_1 = 200. \text{ FT} \]
\[ X_3 = \text{UNDEFINED} \]
\[ M = \text{UNDEFINED} \]
\[ I = \text{UNDEFINED} \]
\[ Q_s = \text{UNDEFINED} \]

\[ X_p = 400. \text{ FT} \quad \text{400} \]
\[ T = 12.1 \text{ FT} \quad \text{12.1} \]
\[ V_B = 15726. \text{ CU YD/100 FT LEVEE STATION} \quad \text{15,726} \]

BERM COST CALCULATION

PERVIOUS BERM WITH COLLECTOR PIPE

\[ V_B = 15726. \text{ CU YD/100 FT LEVEE STATION} \]
\[ \text{UNIT COST} = ? \quad \text{NO RECENT CONSTRUCTION EXPERIENCE} \]
\[ \text{TOTAL COST} = ? \quad \text{NO RECENT CONSTRUCTION EXPERIENCE} \]
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. S

OUTPUT DATA FOR BERM ANALYSIS

SAND BERM

X1 = 200. FT
X3 = UNDEFINED
N = UNDEFINED
I = UNDEFINED
Qs = UNDEFINED
Xs = 400. FT
T = 12.1 FT
VB = 15726. CU YD/100 FT LEVEE STATION

BERM COST CALCULATION

SAND BERM

VB = 15726. CU YD/100 FT LEVEE STATION
UNIT COST = $ 3.75 /CU YD
TOTAL COST = $ 58972.00 /100 FT LEVEE STATION

59,300
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

OUTPUT DATA FOR BLANKET ANALYSIS

\[ \text{Hand Calculations} \]

\[ X_1 = 4734. \text{ FT} \]
\[ X_3 = 2048. \text{ FT} \]
\[ M = 0.3930 \times 10^{-2} \]
\[ I = 700 \text{ GPM/100 FT} \]
\[ Q_s = 58. \text{ GPM/100 FT} \]
\[ X_R = 4734. \text{ FT} \]
\[ L_B = 800. \text{ FT} \]
\[ K_B = 0.1000 \times 10^{-4} \text{ CM/S} \]
\[ Z_B = 3.6 \text{ FT} \]
\[ V_{RB} = 10596. \text{ CU YD/100 FT LEVEE STATION} \]

BLANKET COST CALCULATION

\[ V_{RB} = 10596. \text{ CU YD/100 FT LEVEE STATION} \]
\[ \text{UNIT COST} = \$ 1.20 / \text{CU YD} \]
\[ \text{TOTAL COST} = \$ 12715.00 /100 \text{ FT OF LEVEE STATION} \]

\[ \text{TOTAL COST} \]

\[ 12,800 \]
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

OUTPUT DATA FOR CUTOFF ANALYSIS

\[
\begin{align*}
DC/D &= 0.950 \\
X_1 &= 200. \text{ FT} \\
X_3 &= 2048. \text{ FT} \\
M &= 1.058 \times 10^{-01} \\
I &= 1.799 \\
Q_s &= 146. \text{ GPM/100 FT} \\
\end{align*}
\]

CUTOFF COST CALCULATION

\[
\begin{align*}
\text{DEPTH} &= 52. \text{ FT} \\
\text{COST} &= \$ 15600.00 / 100 \text{ FT OF LEVEE STATION} \quad \$ 15,600
\end{align*}
\]
**PROJECT : PROGRAM DEVELOPMENT**
**STATION : X-SECT. 5**

**OUTPUT DATA FOR RELIEF WELL ANALYSIS**

<table>
<thead>
<tr>
<th>P</th>
<th>ASEL</th>
<th>WBAR</th>
<th>QW</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>.250</td>
<td>95</td>
<td>10</td>
<td>372.46</td>
<td>3707.00</td>
</tr>
<tr>
<td>.375</td>
<td>127</td>
<td>15</td>
<td>475.45</td>
<td>3229.00</td>
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<tr>
<td>.500</td>
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<td>20</td>
<td>575.45</td>
<td>3072.00</td>
</tr>
<tr>
<td>.625</td>
<td>171</td>
<td>25</td>
<td>682</td>
<td>3051.00</td>
</tr>
<tr>
<td>.750</td>
<td>187</td>
<td>30</td>
<td>731</td>
<td>3101.00</td>
</tr>
<tr>
<td>.875</td>
<td>199</td>
<td>35</td>
<td>800</td>
<td>3193.00</td>
</tr>
<tr>
<td>1.000</td>
<td>209</td>
<td>40</td>
<td>819</td>
<td>3311.00</td>
</tr>
</tbody>
</table>

Hand Calculations

MINIMUM COST $3051.00
COST SUMMARY FOR ALL CONTROL MEASURES
---------------------------------------------

<table>
<thead>
<tr>
<th>TYPE</th>
<th>VOLUME</th>
<th>UNIT COST</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNSPECIFIED BERM</td>
<td>NOT CALCULATED</td>
<td>$1.30</td>
<td>$20443.00</td>
</tr>
<tr>
<td>IMPERVIOUS BERM</td>
<td>15726.</td>
<td>$1.30</td>
<td>$20443.00</td>
</tr>
<tr>
<td>SEMIPERVIOUS BERM</td>
<td>15726.</td>
<td>$1.30</td>
<td>$20443.00</td>
</tr>
<tr>
<td>PERVIOUS BERM</td>
<td>15726.</td>
<td>$1.30</td>
<td>$20443.00</td>
</tr>
<tr>
<td>SAND BERM</td>
<td>15726.</td>
<td>$3.75</td>
<td>$58972.00</td>
</tr>
<tr>
<td>ROCK ISLAND BERM</td>
<td>NOT CALCULATED</td>
<td>$3.75</td>
<td>$58972.00</td>
</tr>
<tr>
<td>RIVERSIDE BLANKET</td>
<td>10596.</td>
<td>$1.20</td>
<td>$12715.00</td>
</tr>
</tbody>
</table>

CUTOFF
-------

RELIEF WELL - LOWEST COST
---------------------------

DC/D = 0.950
DEPT = 25. FT
SPAC = 171. FT
TOTAL = $ 15600.00

TOTAL = $3051.00
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 5 by I2wC

Analysis of piezometer data

Date 5/9/73
Piez. No. Dist from Reading l h
B.3 +20 175.3 420 10.8
B.4 +200 174.1 200 9.6
B.5 +400 172.4 0 0
B.6 +600 161.5 200 10.6
B.7 +985 172.5 585 9.7
River 178.2 13.7

Using data for piezometers B.3 & B.4:

\[ h = 420 \cdot 200 = 220 \]
\[ b = 2500 \cdot 10^{-4} \text{ cu} \cdot \text{acc} \]
\[ a = 400 \text{ ft} \]
\[ L_2 = 600 \text{ ft} \]
\[ h_x = 11.5 \text{ ft} \]

\[ M = \frac{1.9 - 9.2}{l} = 0.00545 \]

\[ Q = 1472 \text{ M \delta} = 1472 (0.00545) x 15 \times 40 = 50 \text{ qpm} / 100 \text{ ft} \]

\[ S = \frac{L_1 + h_x - h_1}{M} = 420 + 13.7 - 10.8 = 952 \]

\[ x_1 = S - L_2 = 952 - 600 = 352 \text{ ft} \]

\[ x_2 = \frac{h_1}{M} - L_1 = \frac{10.8}{0.00545} - 420 = 1542 \text{ ft} \]

\[ h_0 = \frac{h + (x_3)}{x_1 + L_2 + X_3} = \frac{13.7 (1562)}{352 + 600 + 1562} = 8.5 \]

\[ i = \frac{h_0}{x_3} = \frac{8.5}{11.5} = 0.74 \]

E159
PIEOMETER LOCATIONS

# OF PIEZOMETERS = 5

<table>
<thead>
<tr>
<th>PND</th>
<th>PSTA</th>
<th>POFF</th>
<th>TIPEL</th>
<th>TREL</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-3</td>
<td>58+10</td>
<td>20U/S</td>
<td>140.0</td>
<td>200.0</td>
</tr>
<tr>
<td>B-4</td>
<td>58+20</td>
<td>200D/S</td>
<td>145.0</td>
<td>175.0</td>
</tr>
<tr>
<td>B-5</td>
<td>58+30</td>
<td>400D/S</td>
<td>140.0</td>
<td>165.0</td>
</tr>
<tr>
<td>B-6</td>
<td>58+40</td>
<td>600D/S</td>
<td>135.0</td>
<td>165.0</td>
</tr>
<tr>
<td>B-7</td>
<td>58+50</td>
<td>985D/S</td>
<td>130.0</td>
<td>165.0</td>
</tr>
</tbody>
</table>

PIEOMETER READINGS

# OF PZ READINGS = 5

<table>
<thead>
<tr>
<th>PND</th>
<th>PDTRD</th>
<th>PREAD</th>
<th>POOLRD</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-3</td>
<td>05/09/1973</td>
<td>175.3</td>
<td>178.2</td>
</tr>
<tr>
<td>B-4</td>
<td>05/09/1973</td>
<td>174.1</td>
<td>178.2</td>
</tr>
<tr>
<td>B-5</td>
<td>05/09/1973</td>
<td>172.4</td>
<td>178.2</td>
</tr>
<tr>
<td>B-6</td>
<td>05/09/1973</td>
<td>167.3</td>
<td>178.2</td>
</tr>
<tr>
<td>B-7</td>
<td>05/09/1973</td>
<td>172.5</td>
<td>178.2</td>
</tr>
</tbody>
</table>
PROJECT NAME: PROGRAM DEVELOPMENT
STATION: X-SECT. 5

PZ UNDERSEEPAGE ANALYSIS
INITIAL CONDITIONS

\[ x_1 = 351.7 \text{ FT} \]
\[ x_3 = 1560.0 \text{ FT} \]
\[ M = 0.5455 \times 10^{-2} \]
\[ I = 0.740 \]
\[ Q_S = 80.4 \text{ GPM/100 FT} \]

\[ H = 13.7 \text{ FT} \]
\[ h_1 = 10.8 \text{ FT} \]
\[ h_2 = 9.6 \text{ FT} \]
\[ H_0 = 8.5 \text{ FT} \]
\[ S = 951.7 \text{ FT} \]
Cross Section 6
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 6 by WC3

Well Analysis

Date 7 Aug 86
Page 1 of 9

Well

\( D_p = 0.67 \) ft
\( R_m = 1.0 \) ft
Plastic pipe
\( \varepsilon = 0.0001 \)

\[ H = 30 \text{ ft} \]
\[ Z_{b1} = 6 \text{ ft} \]
\[ \lambda_{b1} = 3 \times 10^{-4} \text{ cm/sec} \]

\[ L_1 = 980 \text{ ft} \]
\[ Z_{b2} = 6 \text{ ft} \]
\[ \lambda_{b2} = 3 \times 10^{-4} \text{ cm/sec} \]

\[ L_2 = 220 \text{ ft} \]
\[ d = 100 \text{ ft} \]

\[ L_3 = \text{infinity} \]
\[ d_1 = 10 \text{ ft} \]
\[ \lambda_{H1} = 125 \times 10^{-4} \text{ cm/sec} \]

\[ H_{el} = 0.33 \text{ ft} \]
\[ d_2 = 15 \text{ ft} \]
\[ \lambda_{H2} = 200 \times 10^{-4} \text{ cm/sec} \]

\[ d_3 = 7.5 \text{ ft} \]
\[ \lambda_{H3} = 1200 \times 10^{-4} \text{ cm/sec} \]

\[ \phi = \text{saturated weight of blanket = 50 lb/cu ft} \]

Transform the three-layer pervious foundation into a homogeneous, isotropic, non-layered foundation

\[ D = \text{transformed thickness} = \left( \frac{N}{\varepsilon} d \lambda H \times \frac{N}{\varepsilon} d / \lambda \nu \right)^{1/2} \]

\[ = \left( (10 \times 125 \times 10^{-4} + 15 \times 200 \times 10^{-4} + 75 \times 1200 \times 10^{-4}) (10 \times 125 \times 10^{-4} + 15 \times 100 \times 10^{-4} + 75 \times 600 \times 10^{-4}) \right)^{1/2} \]

\[ = (0.125 + 0.3 + 0.9)(2000 + 1500 + 1250)^{1/2} \times ((9.425)(4750))^{1/2} \]

\[ = 211.6 \text{ ft} \quad \text{use} \quad 210 \text{ ft} \]

\[ K_4 = \text{transformed permeability} = \left( \frac{N}{\varepsilon} d \lambda H / \frac{N}{\varepsilon} d / \lambda \nu \right)^{1/2} \]

\[ \text{using values from above computation} \]

\[ K_4 = \left( \frac{9.425}{4750} \right)^{1/2} = 0.0445 \text{ cm/sec or} \quad 4.45 \times 10^{-4} \text{ cm/sec} \]

\[ \text{use} \quad 450 \times 10^{-4} \text{ cm/sec} \]

E166
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 6 by wgs

Well Analysis

Date 8 Aug 96
Page 2 of 9

Solve for $x_1$ and $x_3$

$$x_1 = \frac{\tanh C_{br} L_1}{C_{br}} \quad \text{where} \quad C_{br} = \left( \frac{h_{br}}{K_f Z_{br} D} \right)^{1/2} = \left( \frac{3 \times 10^{-4}}{480 \times 10^{-4} \times 6 \times 210} \right)^{1/2} = 0.00230$$

$$x_1 = \frac{\tanh (0.00230)(980)}{0.00230} = 425 \text{ ft}$$

$$x_3 = \frac{1}{C_{bl}} \quad \text{where} \quad C_{bl} = \left( \frac{h_{bl}}{K_f Z_{bl} D} \right)^{1/2} \text{ in this case has the same numerical value as } C_{br}$$

$$x_3 = \frac{1}{0.00230} = 435 \text{ ft}$$

Then $S = x_1 + L_2 = 425 + 220 = 645 \text{ ft}$

Select a factor of safety $F_S = 1.5$

$$C_{cr} = \frac{\%}{62.4} = \frac{59}{62.4} = 0.98$$

$$C_a = C_{cr} / F_S = 0.98 / 1.5 = 0.53$$

Then, the allowable head at the landside toe

$$H_a = C_a Z_{bl} = 0.53 \times 6 = 3.2 \text{ ft}$$

Start the well design computations

Prescriptive well penetration to take values from 0.25 to 1 in steps of 0.125

$P = 0.25$ and $\alpha = 25$

Assume $H_{av} = H_a = 3.2$

$$\Delta M = \frac{H - H_{av}}{S} - \frac{H_{av}}{x_3} = \frac{30 - 3.2}{645} - \frac{3.2}{435} = 0.0416 - 0.0074 = 0.0342$$

Compute a trial well discharge

$$Q_w = 14.724 \times 0.0342 = 0.497 \times 6 = 0.0285 \times 210$$

$$Q_w = 119 \text{ gpm}$$

Using this $Q_w$, calculate the head loss in the well, $H_w$
Levee Underseepage Computdr Program

Hand Computations used for Verification

Cross Section No. 6 by WGS

Well Analysis

Date 8 Aug 86

Page 3 of 9

\[ H_w = H_e + H_s + H_r + H_v + H_l \]

\[ Q_w = Q_w + h_f \left( \frac{N}{200} \right) + h_s \left( \frac{LR}{100} \right) + \frac{V^2}{2g} + 0.33 \]

\[ LR = \text{length of riser pipe} = Z_{4g} + H_e + 6 + 0.3 = 6.33 \text{ ft} \]

First, solve for \( W \), the actual well penetration in the pervious stratum

\[ \sum_0 W \cdot d \cdot h = P \sum_0 N \cdot d \cdot h_n \]

The sum \( \sum_0 d \cdot h_n \) was solved previously

\[ = 0.25(9.425) = 2.356 \]

Then \( d_1 \cdot h_1 + d_2 \cdot h_2 + d_3 \cdot h_3 = 2.356 \)

and \( x \cdot h_3 = 2.356 - 0.125 - 0.3 \)

\[ x = \frac{1.931}{0.1200} = 16 \text{ ft} \]

And \( W = d_1 + d_2 + x = 10 + 15 + 16 = 41 \text{ ft} \)

Similar computations for other values of \( P \) yield

<table>
<thead>
<tr>
<th>( P )</th>
<th>( W, \text{ ft} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>41</td>
</tr>
<tr>
<td>0.375</td>
<td>51</td>
</tr>
<tr>
<td>0.50</td>
<td>61</td>
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<td>0.625</td>
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<td>0.875</td>
<td>90</td>
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<tr>
<td>1.0</td>
<td>100</td>
</tr>
</tbody>
</table>

Then for this case \( P = 0.25 \), \( Q_w = 119 \), \( W = 41 \), \( LR = 6.33 \)

\[ H_w = \frac{119}{20 \times 41} + h_f \left( \frac{41}{200} \right) + h_s \left( \frac{6.33}{100} \right) + \frac{V^2}{2g} + 0.33 \]

Next calculate the friction head loss in the well pipe, \( h_f \)

\[ h_f = f \times \frac{100}{D_p} \times \frac{V^2}{2g} = f \left( \frac{0.000012523 Q_w}{D_p^8} \right) \]

The friction factor, \( f \), is determined from the Colebrook-White equation which requires inputs of \( D_p \), \( \varepsilon \), roughness factor, and Reynolds number, \( Re \).

For this computation \( D_p = 0.67 \), \( \varepsilon = 0.001 \) for plastic pipe.
Levee Underseepage Computer Program

Hand Computations used for Verification Cross Section No. 6 by WGS

Well Analysis Date 8 Aug 86 Page 4 of 9

Reynolds number \( Re = \frac{VDp}{\nu} \)

Where \( \nu \) = viscosity of water, for this computation = \( 1.21 \times 10^{-5} \) ft/sec @ 60°F

\[ Re = \frac{0.003284 \times Qw \times Dp}{1.21 \times 10^{-5} \times D_p^2} = \frac{234.7 \times Qw}{Dp} = 4.2 \times 10^4 \]

Enter the Moody diagram to solve for \( f \)
Inputs are \( Re = 4.2 \times 10^4 \) and \( \nu_p = 0.00015 \)

From the diagram read \( f = 0.022 \)

Then \( h_f = 0.022 \left( \frac{0.000324 \times 23 \times (119)^2}{(0.67)^4} \right) = \frac{0.1253 \times 1.4161}{0.135} \)

\[ h_f = 0.3 \text{ ft}/100 \text{ ft of pipe} \]

And \( H_w = \frac{119}{20 \times 41} + 0.03 \left( \frac{41}{200} \right) + 0.03 \left( \frac{0.3}{100} \right) + \frac{0.1253 \times 10^{-6} \times (119)^2}{(0.67)^4} + 0.33 \]

\[ = 0.145 + 0.003 + 0.002 + 0.004 + 0.33 \]

\[ = 0.487 \text{ ft}, \text{ round off to 0.5 ft}. \]

Get a new value for \( H_{av} = H_w + h_{av} = 0.5 + h_{av} \)

\[ h_{av} = \frac{h \theta_{av}}{\frac{5}{a} + \left( \frac{5 + x_3}{x_3} \right) \theta_{av}} \]

Where \( h = H - H_w \left( \frac{5 + x_3}{x_3} \right) = 30 - 0.5 \left( \frac{6.45 + 4.35}{4.35} \right) = 30 - 0.5(2.48) \)

\[ h = 28.0 \]

Calculate \( \theta_{av} \) from equations for the nomograph in E8.55-11, Plate 1.
(Note: the nomograph does not extend far enough to cover this case, so a numerical solution is made)

\[ X = 5.0030644 - 15.372062 (\log \frac{P_a}{P_k}) + 13.978129 (\log \frac{P_a}{P_k})^2 \]

\[ = 5.0030644 - 15.372062 \log \frac{500}{50} + 13.978129 \left( \log \frac{50}{50} \right)^2 \]

\[ = 5.0030644 - 14.293785 + 11.934191 = 2.7334705 \]

\[ Y = 0.0093427 - 0.0511538 (D_p) - 0.385317 (10^7 \frac{P_a}{P_k}) \]

\[ = 0.0093427 - 0.42969192 - 0.35603291 = -0.77667832 \]

\[ M = 0.996105 \left( 0.364013 \right) \]

\[ = 0.25 \times 0.996105 \left( 0.364013 \right) = 0.4482171 \]
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 6 by WGS

Well Analysis

Date 14 Aug 1986

Page 5 of 9

\[ F = \log \left( \frac{x}{a/f_w} \right) = \log \left( \frac{2.7334705}{25/1} \right) = -0.96122 \]

Then \( \theta_m = Y - (M F) \)

\[ = 0.77667832 - (1.4482171 \times -0.96122) \]

\[ = 0.61538 \quad \text{round off to} \quad 0.61 \]

Next calculate \( \theta_m \) in a similar manner

\[ x_1 = 3.1831982 + 4.2595614/(10a) \]

\[ = 3.1831982 + 4.2595614/(210) \]

\[ = 3.6902888 \]

\[ Y_1 = (0.14273191)(\frac{P}{a})^0.56922597 \]

\[ = (0.14273191)(\frac{210}{15})^{-0.56922597} \]

\[ = 0.0425 \]

\[ F_1 = \log \left( \frac{x_1}{a/f_w} \right) = \log \left( \frac{3.6902888}{25/1} \right) = 0.83087965 \]

Then \( \theta_m = Y_1 - (M F_1) \)

\[ = 0.0425 - (1.4482171 \times 0.83087965) \]

\[ = 1.245 \quad \text{round off to} \quad 1.25 \]

And, \( \hat{h}_{av} = \frac{288 \times 0.61}{65 \times (2.48)0.61} = 0.64 \)

and \( H_{av} = 0.5 + 0.64 = 1.14 \quad \text{round off to} \quad 1.1 \)

ft

Calculate a new \( \Delta M \) using the new \( H_{av} \)

\[ \Delta M = \frac{H - H_{av}}{3} - \frac{H_{av}}{x_3} = \frac{30 - 1.1}{645} - \frac{1.1}{435} = 0.0418 \]

Then \( Q_w = 14.724 \times 25 \times 0.0418 \times 0.045 \times 210 \)

\[ = 145 \text{ gpm} \]

Using \( Q_w = 145 \) and recalculating the head loss, \( H_w \) still equals 0.5

\[ h_m = a \Delta M \theta_m = 25 \times 0.0418 \times 1.25 = 1.31 \]

and \( H_m = H_w + h_m = 0.5 + 1.31 = 1.81 \) ft

However, \( h_w = 3.2 \) ft, which is greater than \( H_m = 1.81 \) ft. So, increase \( a \) and recalculate.
Levee Underseepage Computer Program

Hand Computations used for Verification Cross Section No. 4 by Well 4

Well Analysis Date 14 Aug 1986

Page 6 of 9

Let \( a = 50 \) for \( P = 0.25 \)

Assume \( H_{av} = h_a = 3.2 \) \( \Delta M \) remains 0.0342

Trial \( Q_w = 14.724 \times 50 \times 0.0342 \times 0.045 \times 210 \)

\( Q_w = \frac{238}{9} \) gpm

Calculate \( H_w = \frac{Q_w}{20} \times h_s \left( \frac{25}{200} \right) + h_s \left( \frac{L_P}{100} \right) + \frac{V^2}{2g} + 0.33 \)

\[ h_s = f \left( \frac{0.000012523 Q_w}{D_p^5} \right) \]

To get \( f \), \( Re = \frac{234.7 Q_w}{D_p} = \frac{234.7 \times 238}{0.67} = 8.3 \times 10^4 \)

\( \frac{D_p}{D_p} \) remains 0.00015

From the Moody diagram \( f = 0.020 \)

Then \( h_s = 0.02 \left( \frac{0.000012523 \times 238}{0.67} \right) = 0.105 \) ft/100 ft of pipe Say 0.1

And \( H_w = \frac{238}{20} + 0.1 \left( \frac{41}{200} \right) + 0.1 \left( \frac{6.33}{100} \right) + 0.1 \left( \frac{12523 \times 10^6 (238)^2}{0.67} \right) + 0.33 \)

\[ = 0.29 + 0.02 + 0.006 + 0.035 + 0.33 = 0.68 \text{ round to 0.7} \]

Then \( h = H - H_w \left( \frac{S + K}{K} \right) = 30 - 0.7 (2.48) = 28.3 \)

From the nomograph, Plate 1 in EB 55 11, for \( \theta_a = 4.2 \), \( P = 0.25 \), \% \( r_w = 50 \)

\( \theta_{av} = 2.68 \quad \text{and} \quad \theta_m = 1.65 \)

\[ h_{av} = \frac{h \theta_{av}}{S + \left( \frac{S + K}{K} \right) \theta_{av}} = \frac{28.3 \times 2.68}{645 + \left( \frac{645}{50} \right) 2.68} = 3.9 \]

and \( H_{av} = H_w + h_{av} = 0.7 + 3.9 = 4.6 \)

Calculate new \( \Delta M \) using the new \( H_{av} \)

\[ \Delta M = \frac{H - H_{av}}{S - \frac{K}{K}} = \frac{30 - 4.6 - 4.6}{645 - 439} = 0.0288 \]

Then the new \( Q_w \)

\[ Q_w = 14.724 \times 50 \times 0.0288 \times 0.045 \times 210 \]

\[ = \frac{200}{9} \text{ gpm} \]

Using \( Q_w = 200 \) and calculating the head loss, \( H_w = 0.6 \)

\[ h_m = \Delta M \theta_m = 50 \times 0.0288 \times 1.65 = 2.4 \]

\[ H_m = H_w + h_m = 0.6 + 2.4 = 3.0 \text{ ft} \]
Since $H_m = 3.0$ ft is only slightly less than $h_a = 3.2$ ft, it is
considered that for $P = 0.25$, $a_{361} = 50$ ft and $Q_w = 200$ gpm.

This trial assumes $P = 0.37$ and $w = 50$.
Since for $P = 0.25$ the $a_{361} = 50$, it is not considered necessary to
calculate for $a = 25$ for this case.
Start with $a = 50$.
Assume $H_a = h_a = 3.2$.

Then, from previous calculation (Page 2) $ΔM = 0.0342$

Compute a trial well discharge

$Q_w = 14.724 \times 50 \times 0.0342 \times 0.045 \times 2.10 = 239$ gpm

Using this $Q_w$, calculate head loss, $H_w$ (see Page 3 for equation)

$H_w = \frac{239}{20 \times 50} + h_f \left( \frac{31}{100} \right) + h_f \left( \frac{6.33}{100} \right) + \frac{0.12523 \times 10^{-6}(239)^2}{(0.67)^4} + 0.33$

To get $h_f$, first get $Re = \frac{234.7Q_w}{D_p} = \frac{234.7 \times 239}{0.67} = 2 \times 10^4$

$\frac{D_p}{D_p} = 0.00015$

From the Moody diagram read $f = 0.021$

Then $h_f = f \left( \frac{0.00000000012523 \times 239}{D_p^4} \right) = 0.111 \left( \frac{0.00000012523 \times Q_w}{D_p^4} \right) = 0.11$

Substituting $h_f$ in equation for $H_w$

$H_w = 0.239 + 0.028 + 0.007 + 0.035 + 0.33 = 0.64$ say 0.6 ft

From the nomograph Plate 1, EB 55-11 for $P = 0.37$ $h_a = 4.2$ $\frac{h_a}{Q_w} = 50$

$\Theta_a = 1.66 \quad \Theta_m = 1.1$

$h = H - H_w \left( \frac{54 + 1/2}{H_3} \right) = 30 - 0.6(2.88) = 28.5$

$h_a = \frac{28.5 \times 1.66}{54 + 1/2} = 2.78$ say 2.9

and $H_a = H_w + h_a = 0.6 + 2.9 = 3.4$ ft.

Calculate a new $ΔM = \frac{30 - 3.4}{645} - \frac{3.4}{435} = 0.0332$

Calculate a new $Q_w = 14.724 \times 50 \times 0.0332 \times 0.045 \times 2.10 = 231$ gpm

Assume no change in head loss $H_w = 0.6$

$h_m = a ΔM \Theta_m = 50 \times 0.332 \times 1.1 = 1.8$

and $h_m = 0.6 + 1.8 = 2.4$ which is less than $h_a = 3.2$

Need to try the next larger well spacing $a = 75$.
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 6 by WGS

Well Analysis

Date 15 Aug 1986

Page 8 of 9

This trial assumes \( P = 0.37 \) \( \psi = 50 \) and \( \alpha = 75 \)

Assume \( Ha_0 = 3.2 \)

From previous calculations (page 2) \( \Delta M = 0.0342 \)

Compute a trial well discharge

\[
Q_w = 14.724 \times 75 \times 0.0342 \times 0.045 \times 210 = 357 \text{ gpm}
\]

Calculate head loss, \( H_w \) (see page 3 for equation)

\[
H_w = \frac{357}{20 \times 51} + \frac{61}{200} + \frac{4.33}{100} + \frac{0.12523 \times 10^{-4}(357)^2}{(0.67)^4}
\]

To get \( hf \), first get

\[
\frac{Re}{D_p} = 0.00015
\]

From the Moody diagram read \( f = 0.018 \)

Then

\[
hf = 0.018 \left( \frac{0.00012523 \times 357}{(0.67)^5} \right) = 0.213
\]

Substituting \( hf \) into equation for \( H_w \)

\[
H_w = 0.357 + 0.053 + 0.013 + 0.079 + 0.33 = 0.83 \text{ say 0.8}
\]

From the nomograph Plate I, \( E055-11 \) for \( P = 0.37 \) \( \Psi = \Psi_0 = 75 \)

\[
\Theta_m = 1.85 \quad \Theta_m = 1.25
\]

\[
h = H - H_w \left( \frac{5 + 3 \eta}{\eta_0} \right) = 30 - 0.8(2.48) = 28.0
\]

\[
H_{av} = \frac{2.8 \times 1.59}{4.3 + (2.48)1.59} = 3.6
\]

and \( H_{av} = 0.8 \times 3.6 = 4.4 \)

Calculate a new \( \Delta M = \frac{30 - 4.4 \times 4.4}{643} = 0.0295 \)

and new \( Q_w = 14.724 \times 75 \times 0.0295 \times 0.045 \times 210 = 308 \text{ gpm} \)

Check \( H_w \) to see if there is any change for \( Q_w = 308 \)

\[
H_w = \frac{308}{20 \times 51} + 0.158 \left( \frac{51}{200} \right) + 0.158 \left( \frac{6.33}{100} \right) + \frac{0.12523 \times 10^{-4}(357)^2}{(0.67)^4} + 0.33
\]

based on a new \( hf \) calculated to be 0.158

\[
H_w = 0.308 + 0.039 + 0.01 + 0.059 + 0.33 = 0.7
\]

\[
h_m = \Delta M \quad \Theta_m = 75 \times 0.0295 \times 1.25 = 2.76 \text{ say 2.8 ft}
\]

and \( H_m = 0.7 + 2.8 = 3.5 \text{ ft which is slightly greater than } Ha_0 = 3.2 \)

Interpolate between \( H_m \) values for \( \alpha = 50 \) and \( \alpha = 75 \) to get \( a_{se} \)

\[
a_{se} = \left( \frac{H_a-H_{av}}{H_{av}+H_{av}} \right) (a_{75}-a_{60}) + a_{60} = \left( \frac{3.2 - 2.4}{3.5 - 2.4} \right) (75 - 50) + 50 = 68
\]

Then \( Q_w = 14.724 \times 68 \times 0.0295 \times 0.045 \times 210 = 270 \text{ gpm} \)

Summarizing, for \( P = 0.37 \) \( a_{se} = 68 \text{ ft} \quad Q_w = 270 \text{ gpm} \)
Levee Underseepage Computer Program
Hand Computations used for Verification
Cross Section No. 6 by 4

Well Analysis

Date 19 Aug 1986
Page 9 of 9

Similar computations to those above were made for
P = 0.25, 0.375, 0.5, 0.625, 0.75, 0.875, and 1. The values calculated
for all penetrations are listed below:

<table>
<thead>
<tr>
<th>P</th>
<th>a_se</th>
<th>Qw</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>0.375</td>
<td>68</td>
<td>270</td>
</tr>
<tr>
<td>0.5</td>
<td>77</td>
<td>321</td>
</tr>
<tr>
<td>0.625</td>
<td>89</td>
<td>396</td>
</tr>
<tr>
<td>0.75</td>
<td>97</td>
<td>459</td>
</tr>
<tr>
<td>0.875</td>
<td>103</td>
<td>513</td>
</tr>
<tr>
<td>1.0</td>
<td>107</td>
<td>522</td>
</tr>
</tbody>
</table>

For each of the above-listed conditions the cost of wells per 100-ft station
was calculated.

DR - drilling through top stratum = $20/ft
DP - drilling through previous foundation = $16/ft
RP - riser pipe - diameter D = 0.67 ft
  Plastic pipe = $30/ft
WS - well screen, D = 0.67 ft
  Plastic screen = $85/ft
FL - filter = $12/ft
BF - backfill = $400 lump sum
WC - well cover = $300 lump sum
WD - well development and test = $1000 lump sum

Then the Cost for one well, Cw

Cw = (DR + RP) Z + (DP + WS + FL) w + BF + WC + WD

and the cost per 100-ft section, CWs

CWs = Cw x 100 / a_se

For P = 0.25 a_se = 50  w = 41  Z_b = 6

Cw = (20 + 30) 6 + (16 + 85 + 12) 41 + 400 + 300 + 1000 = 6633

CWs = 6633 x 100 / 50 = $13,266

Similar calculations for all values of P and a_se gave the following
results:

<table>
<thead>
<tr>
<th>P</th>
<th>a_se</th>
<th>w</th>
<th>Qw</th>
<th>Cost per 100 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>50</td>
<td>41</td>
<td>200</td>
<td>$13,266</td>
</tr>
<tr>
<td>0.375</td>
<td>68</td>
<td>51</td>
<td>270</td>
<td>11,411</td>
</tr>
<tr>
<td>0.5</td>
<td>77</td>
<td>61</td>
<td>321</td>
<td>11,545</td>
</tr>
<tr>
<td>0.625</td>
<td>89</td>
<td>71</td>
<td>396</td>
<td>11,262</td>
</tr>
<tr>
<td>0.75</td>
<td>97</td>
<td>80</td>
<td>459</td>
<td>11,381</td>
</tr>
<tr>
<td>0.875</td>
<td>103</td>
<td>90</td>
<td>513</td>
<td>11,815</td>
</tr>
<tr>
<td>1.0</td>
<td>107</td>
<td>100</td>
<td>522</td>
<td>12,430</td>
</tr>
</tbody>
</table>

Lowest cost
PROJECT NAME: PROGRAM DEVELOPMENT
STATION: X-SECT. 6

LEVEE UNDERSEEPAGE ANALYSIS
INITIAL CONDITIONS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>425. FT</td>
</tr>
<tr>
<td>X3</td>
<td>435. FT</td>
</tr>
<tr>
<td>M</td>
<td>0.2778E-01</td>
</tr>
<tr>
<td>I</td>
<td>2.013</td>
</tr>
<tr>
<td>Qs</td>
<td>387. GPM/100 FT</td>
</tr>
<tr>
<td>H0</td>
<td>12.1 FT</td>
</tr>
<tr>
<td>$</td>
<td>0.1944</td>
</tr>
</tbody>
</table>
GENERAL CONTROL MEASURE INPUT DATA

LTE = 106 FT
H = 30 FT
LTO = 100 FT RTO = 120 FT

L1 = 980 FT ENTRANCE = OPEN
L3 = INFINITE FT EXIT = INFINITE

D = 100 FT DD = 210 FT
ZBL = 6 FT KBL = 0.0003 CM/S
ZBR = 6 FT KBR = 0.0003 CM/S
ZT = 6 FT KF = 0.045 CM/S
ZL = 6 FT

SUBWT = 50. LB/CU FT

SUPPLEMENTAL CONTROL MEASURE INPUT DATA

BERM RIVERSIDE BLANKET

F9B = UNDEFINED IA = UNDEFINED
I0B = UNDEFINED M3R = UNDEFINED
I1 = UNDEFINED M4 = UNDEFINED
M1 = UNDEFINED
M3B = UNDEFINED

CUTOFF RELIEF WELL

NO SPECIAL INPUT REQUIRED
FSW = UNDEFINED
IOW = 0.534
RW = 1.0 FT
DP = 0.67 FT
RUFF = 0.0001
VISCOS = 0.0000121 GAL*FT/SEC
J = UNDEFINED %
HEL = 0.33 FT
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECTION 6

OUTPUT DATA FOR RELIEF WELL ANALYSIS

<table>
<thead>
<tr>
<th>P</th>
<th>ASEL</th>
<th>WBAR</th>
<th>QW</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>.250</td>
<td>50.</td>
<td>50</td>
<td>41.</td>
<td>217.20 $</td>
</tr>
<tr>
<td>.375</td>
<td>65.</td>
<td>67</td>
<td>51.</td>
<td>271.20 $</td>
</tr>
<tr>
<td>.500</td>
<td>77.</td>
<td>77</td>
<td>61.</td>
<td>319.20 $</td>
</tr>
<tr>
<td>.625</td>
<td>86.</td>
<td>89</td>
<td>71.</td>
<td>389.20 $</td>
</tr>
<tr>
<td>.750</td>
<td>95.</td>
<td>97</td>
<td>80.</td>
<td>458.20 $</td>
</tr>
<tr>
<td>.875</td>
<td>102.</td>
<td>103</td>
<td>90.</td>
<td>468.50 $</td>
</tr>
<tr>
<td>1.000</td>
<td>108.</td>
<td>107</td>
<td>100.</td>
<td>515.60 $</td>
</tr>
</tbody>
</table>

386

Hand Calculations

MINIMUM

E178
Cross Section 7
Actual section already has Berm.
Section to be analyzed, will be levee without Berm.

Riverside toe of levee is assumed to be El 453.7 and 110 ft landward of old levee center line.
Riverside toe of levee is assumed to be El 452.3 and 70 ft landward of old levee center line.
Landside top stratum is chosen to be 7.4 ft of lean to heavy clay.
Riverside top stratum is chosen to be 6.9 ft of lean to heavy clay.
From Fig. 43 of TR-GL-80-3, the bottom of the pervious stratum is found to be at El 338; \(D = 108\) ft.
By is assumed to be 1500 x 10^{-4} cm/sec.
Based on recommendations in TR-GL-80-3, landside and riverside permeability ratios of 100 and 200 will be used; \(k_{ls} = 15 x 10^{-4} \text{ cm/sec}\), and \(k_{rs} = 7.5 x 10^{-4} \text{ cm/sec}\).

Head for this analysis is arbitrarily chosen to be 22.3 ft.
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 7 by WRUC

Simplified Section, Rock Island example

\[
\begin{align*}
H &= 22.3 \text{ ft} \\
D &= 108 \text{ ft} \\
L_1 &= 300 \text{ ft} \\
L_2 &= 150 \text{ ft} \\
\theta &= 7.4 \text{ ft} \\
\delta' &= 42.4 \text{ ft} \\
\delta &= 53 \text{ ft}
\end{align*}
\]

Initial Conditions

\[
\begin{align*}
\chi_1 &= \tanh \left( \frac{C_{ba} L_1}{C_w} \right), \\
\chi_2 &= \frac{C_{ba}}{\theta} = 184 \text{ ft} \\
\chi_3 &= \frac{1}{C_{ba}} = 252 \text{ ft} \\
\chi_4 &= \frac{1}{0.00254} = 252 \text{ ft} \\
\lambda &= \frac{H}{\theta} = \frac{22.3 \times 252}{184 + 150 + 282} = 9.7 \text{ ft}
\end{align*}
\]

where

\[
\begin{align*}
C_{ba} &= \left( \frac{R_{ba}}{k_4 C_{ba} D} \right)^{1/2} = \left( \frac{1.5 \times 10^{-4}}{1500 \times 6,510} \right)^{1/2} = 0.00254 \\
C_{we} &= \left( \frac{R_{we}}{k_4 C_{we} D} \right)^{1/2} = \left( \frac{7.5 \times 10^{-4}}{1500 \times 7.4108} \right)^{1/2} = 0.00254
\end{align*}
\]

E183
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 7 by Row

Date 5/27/37
Page 3 of 14

Initial conditions (cmid)

\[ M = \frac{H}{x_1 + L_2 + x_3} \times \frac{22.3}{184 + 180 + 262} = 0.0345 \]

\[ Q_3 = \frac{1472 \frac{ft}{min} \times 10^4}{x_1 + L_2 + x_3} \times \frac{22.3 \times 10^2}{184 + 180 + 262} = 823.9 \text{ gpm} \]

Bern analysis

Rock Island procedure (hydraulic sand fill)

\[ FS = \frac{h_0 \times 2t}{h_0 \times t} \quad \text{where} \quad h_0 = \frac{H \times x_3}{x_1 + L_2 + x_3 + L_4} \]

\[ h_4 = 0.44 \times 10^3 = 0.44 (10^3) = 486 \]

\[ h_0 = \frac{22.3 \times 262}{184 + 180 + 262 + 4} = 9.1 \text{ ft} \]

\[ FS = \frac{53 (7.4)}{9.1 (62.4)} = 0.69 \]

Since \( FS < 1.0 \), bern is required

Calculate bern width, \( \overline{X}_{RE} \) and thickness, \( t \)

\[ \overline{X}_{RE} = 10 \times H - L_2 = 10 (22.3) - 180 = 43 \text{ ft} \]

\[ \overline{X}_{RE} \text{ min} = 20 \text{ ft} \quad \therefore \overline{X}_{RE} = 43 \text{ ft} \quad \text{ ok} \]

\[ t = \frac{1.5 \times h_0 \times h_0}{1.5 \times h_0 + t'} = \frac{1.5 \times 62.4 \times 9.1 - 7.4 (53)}{1.5 (62.4) + 53} = 3.1 \text{ ft} \]

\[ X_{min} = 3.0 \text{ ft} \quad \therefore t = 3.1 \text{ ft} \quad \text{ ok} \]

Bern slope, \( m_{L_2} \)

\[ V_8 = \left[ \frac{2}{m_3} + \left( \frac{t + 2}{2} \right) \overline{X}_{RE} + \frac{t^2}{2 \overline{X}_{RE} (m_{L_2} - m_3)} \right] \times 100 \]

\[ V_8 = \left[ \frac{2}{0.26} + \left( \frac{3.1 + 2}{2} \right) 43 + \frac{3.1^2}{2 (0.26 - 0.026)} \right] \times 100 = 519 \text{ yr}^3 / 100 \text{ ft of levee station} \]

E184
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 7 by UWC

Date 5/24/67

Page 4 of 14

Bern analysis (cm'd)

Rock Island Bern (cm'd)

Cost

\[
\text{Cost} = V_B \times \text{unit cost}
\]

unit cost hydraulic sand fill = 63.75 \$/yd^3

\[
\text{Cost} = 5.19 \times 63.75 = 1,950 / 100 \text{ ft of levee station}
\]

Sand bern analysis

Semi-pervious bern width

\[
\overline{x}_{sp} = \frac{-A + \sqrt{A^2 - 4 \left(2 + \gamma_0 \left(1 + 5 \gamma \varepsilon - \frac{H}{h_a}\right)\right)}}{2\gamma \varepsilon}
\]

where

\[
A = 6 + 35 \gamma \varepsilon \left(2 - 1\right)
\]

\[
\gamma = \gamma_0 / \gamma_1
\]

where \(
\gamma_0 = 0.8 \gamma 0.035 = 0.35 \gamma 0.035(6.4) = 0.34 \gamma 0.8
\]

\[
\gamma = 0.34 / 0.8 = 0.425
\]

\[
h_a = \gamma_1 \gamma_0 = 0.8 (7.4) = 5.9 \text{ ft}
\]

\[
A = 6 + 35 (324)(0.00354)(0.425 + 1) = 11.51
\]

\[
\overline{x}_{sp} = \frac{-11.51 + \sqrt{11.51^2 - 4 \left(2 + 0.425 \left(1 + 344(0.00354) - \frac{22.35}{5.9}\right)\right)}}{2(0.00354)(2 + 0.425)}
\]

= 192 ft

Pervious bern with collector pipe (width only used for sand bern calculations)

\[
\overline{x}_p = \frac{\gamma_3 \ln \left(\frac{h_0'}{h_a}\right)}{\gamma_3}
\]

where

\[
h_0' = h_0 = \frac{H(x_3)}{x_1 + x_2 + x_3} = \frac{22.3 (252)}{164 + 180 + 252} = 9.7 \text{ ft}
\]

\[
h_a = \gamma_1 \gamma_0 = 0.8 (7.4) = 5.9 \text{ ft}
\]

\[
\overline{x}_p = 252 \ln \left(\frac{9.7}{5.9}\right) = 140 \text{ ft}
\]
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 7 by RWC

Date 5/24/67
Page 5 of 14

Sand beam analysis (cont'd)

\[
\overline{x}_s = \frac{1}{3} \left( \frac{2 \overline{x}_s p + \overline{x}_s p}{1 + \lambda_o} \right) = \frac{1}{3} \left( \frac{2(192) + 140}{1 + 0.2} \right) = 175 \text{ ft}
\]

\[
\text{Trial } x = 1.25 \left( \frac{h_o - 1.25 x}{1 + \lambda_o} \right)
\]

where \( h_o = h_a \left[ 1 + \frac{c_{be} \overline{x}_s}{6} \left( \frac{x + 2}{2} \right) \right]
\]

\[
= 5.9 \left[ 1 + \frac{0.00354(175) + 2 \times 0.35}{6} \right]
\]

\[
= 10.5 \text{ ft}
\]

\[
\text{Trial } x = 1.25 \left( \frac{10.5 - 0.34(174)}{1 + 0.34} \right) = 7.5 \text{ ft}
\]

Check \( m_2 = \frac{\frac{x - L}{2}}{\overline{x}_s - \frac{1}{2} m_2} = \frac{7.5 - 2}{175 - 2} = 0.033 > 0.02 \Rightarrow OK\)

\[
V_b = \left[ \frac{2}{m_3} + \frac{4}{2} \left( \overline{x}_s - \frac{1}{2} m_3 \right) + \frac{4^2}{2(m_1 - m_2)} \right] \frac{100}{27}
\]

\[
= \left[ \frac{2}{0.2} + \frac{7.5 + 2}{2} \left( 175 - \frac{1}{2} \right) + \frac{7.5^2}{2(0.26 - 0.033)} \right] \frac{100}{27}
\]

\[
= 3400 \text{ yd}^3/100 \text{ ft} \text{ of levee station}
\]

Cost = \( V_b \times \text{unit cost} \)

\[
= 3400 \times 4.75 = \$12,750/100 \text{ ft} \text{ of levee station}
\]
Riverside Blanket analysis

\[ x_n = x_3 \left( \frac{H}{h_a} - 1 \right) - L_2 \quad \text{where} \quad h_a^3 \cdot l_a^2 \cdot z_a = 0.7 \times 7.4 = 5.24 \text{ft} \]

\[ = 282 \left( \frac{22.3}{5.2} - 1 \right) - 180 \]

\[ = 747 \text{ ft} \]

Since the distance to the river is only 200 ft, there is no way to build a riverside blanket with an \( x = 747 \text{ ft} \); riverside blanket will not work.

Cutoff analysis, \( \alpha = 0.95 \text{ only} \)

\[ x_1 = 164 \text{ ft}, \quad x_3 = 282 \text{ ft}, \quad L_2 = 180 \text{ ft}; \quad D = 108 \text{ ft} \]

\[ k_4 = 1500 \times 10^{-4} \text{ wp m sec}; \quad Q_5 = \frac{k_4 H}{\varepsilon \phi_m} = \frac{1472 \times 1500 \times 10^{-4} \times 22.3}{108} \text{ gpm} / 108 \text{ ft} \]

\[ \phi_2 = \frac{x_1}{D} = \frac{164}{108} = 1.704 \]

\[ \phi_3 = \ln \left( \frac{1}{1 - \alpha \phi_2} \right) + \frac{L_2 - x_3}{D} = \ln \left( \frac{1}{1 - 0.95} \right) + \frac{180}{108} - 0.95 = 3.712 \]

\[ \phi_4 = \ln \left( \frac{1}{1 - \alpha \phi_2} \right) + \frac{x_3}{D} - \frac{\alpha x_3}{D} = \ln \left( \frac{1}{1 - 0.95} \right) + \frac{282}{108} - 0.95 = 4.657 \]

\[ \varepsilon \phi_m = \phi_2 + \phi_3 + \phi_4 = 1.704 + 3.712 + 4.657 = 10.073 \]

\[ Q_5 = \frac{1472 \times 1500 \times 10^{-4} \times 22.3}{108 \times 10.073} = 4.59 \text{ gpm} / 108 \text{ ft levee sta} \]
Cut-off analysis (con'd)

\[ M = \frac{h_A - h_B}{L} \]

where \( h_A = H \left(1 - \frac{\Phi_2}{2 \Phi_m}\right) = 22.3 \left(1 - \frac{1.704}{10.073}\right) = 18.524 \)

and \( h_B = \frac{L}{L + d_c} (h_A - h_c) \)

Note: For location of \( h_A, \ldots h_D \) see cross section 2, p 50.119.

\[ h_c = H \left(1 - \frac{\Phi_2 + \Phi_3}{2 \Phi_m}\right) = 22.3 \left(1 - \frac{1.704 + 3.712}{10.073}\right) = 10.310 \]

\[ h_B = 18.528 - \frac{150}{1504.95(108)} (18.528 - 10.310) = 13.294 \]

\[ M = \frac{13.294 - 13.254}{180} = 0.0291 \]

\[ i = \frac{h_0}{2x} \]

where \( h_0 = h_c \left(1 - \frac{d_c}{d_c + x}\right) = 10.310 \left(1 - \frac{0.95(108)}{0.95(108) + 2.82}\right) = 7.560 \)

\[ i = \frac{7.560}{7.4} = 1.022 \]

Cost for cut-off, \( d_c/10 = 0.95 \)

\[ d_c + \frac{2}{k} = 0.95(10) + 7.4 = 11.34 \]

Area @ \$5.00 = 15 \times 100 = 1500 \text{ ft}^2

Cost = 1500 \times 5.00 = \$7500

Area @ \$8.00 = (110 - 65) \times 100 = 4500 \text{ ft}^2

Cost = 4500 \times 8.00 = \$36000

Total cut-off cost = \$\frac{55500}{100} = \text{levee sta}
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 7 by PHW

Relief well analysis

P = 0.25, Determine A Sel

\[ \lambda_{aw} = \frac{5}{4S} = \frac{53/62.4}{4} = 0.56 \]

FS = 1.5; \[ \lambda_0 = \frac{\lambda_{aw}}{FS} = \frac{0.56}{1.5} = 0.37 \]

\[ r_m = 1.5 \]

a) \[ h_0 = \lambda_0 r_m = 0.57 (1.4) = 4.22 \text{ ft} \]

b) assume \[ H_{aw} = h_0 = 4.22 \text{ ft} \]

then \[ \Delta M = \frac{H_{aw}}{5} - \frac{H_{aw}}{3} = \frac{22.3 - 4.22}{2.4} = 0.03471 \]

c) assume \[ a = 40 \text{ ft} \]

\[ \Delta w = 14.72 \lambda_{aw} \Delta M \lambda_{aw} D \]

= 14.72 (40)(0.03471)(15)(102)

= 531.9 \text{ pm} \]

d) \[ H_w = 0.60 \text{ ft} \]

e) \[ h_{aw} = H_{aw} - H_w = 4.22 - 0.60 = 3.42 \text{ ft} \]

f) \[ \Theta_{aw} = \frac{h_{aw}}{\Delta M} = 3.42/0.03471 = 98.53 \]

\[ a \quad \Theta_{aw} \]

40 2.46
50 1.97
60 1.64

\[ \Theta_{aw} = 1.93 \]

\[ a = 50 + 10 (4.53) = 51 \text{ ft} \]

\[ \Theta_{aw} = 1.93; \Theta_{m} = 1.53 \]

repeat steps a) to i)

using \[ a = 50 \text{ ft} \]
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 7 by R2W

Date 5/22/67
Page 9 of 14

Relief well analysis (cm/in)

\[ P = 0.25 \ (\text{cm/d}) \]

\[ Q_w = 14.72 \ \text{a} \ \Delta M \ \Delta D = 14.72 (0.03471)(50)(0.15)(108) = 414.9 \ \text{gpm} \]

\[ d_2) \ H_w \ from \ fig. \ 61 = 0.92 \]

\[ e_2) \ h_{aw} = H_w + H_0 = 4.14 - 0.52 = 3.62 \]

\[ f_2) \ \theta_{aw} = h_{aw} / \Delta M = 2.30 / (0.03471) = 65.07 \]

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \theta_{aw} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>2.38</td>
</tr>
<tr>
<td>50</td>
<td>1.90</td>
</tr>
<tr>
<td>60</td>
<td>1.58</td>
</tr>
</tbody>
</table>

\[ g_2) \ \text{from fig. 60} \]

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \theta_{aw} )</th>
<th>( \Delta D )</th>
<th>( \Delta a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>2.00</td>
<td>2.70</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1.94</td>
<td>2.14</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>1.50</td>
<td>1.50</td>
<td></td>
</tr>
</tbody>
</table>

\[ h_2) \ \text{by inspection} \ \theta_{aw} = 1.95 \ \text{and} \ a = 40 + 10 (43/41) = 49 \ \text{ft} \]

\[ \text{Compare 49 ft with first trial well spacing} \ a = 50 \ \text{ft} \]

\[ \text{good enough} \ a \ \text{set} = 49 \ \text{ft} \]

\[ Q_w = 14.72 \ \Delta M \ \Delta D = 14.72 (0.03471)(49)(0.15)(108) = 406.9 \ \text{gpm} \]

Cost per well (plastic pipe and screen)

\[ C_W = (LRT + RP) + (DP + WS + FL) \ + BF + WC + WD \]

\[ = (20 + 30) 7.4 + (18 + 85 + 12) \times 10^3 + 400 + 300 + 1000 \]

\[ = 370 + 3051 + 1700 = 5121 \ \text{/ well} \]

Cost per 100 ft of levee station

\[ C_{WS} = C_W (100 / \text{acre}) = 5121 (100 / 43) = 10450 / 100 \text{ft} \]
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. by ZUQ

Relief well analysis (cont.)

\[ P = 0.50 \]

\[
\text{from above } h_a = 4.22 \text{ ft, } H_a = 4.22 \text{ ft, } \Delta M = 0.03471
\]

c) assume \( a = 75 \text{ ft} \); \( Q_a = 14.72 \times \Delta M \times 4 \text{ D} \)

\[
= 14.72 \times (75) \times (0.03471) \times (10^8)
\]

\[
= 520.9 \text{ ppm}
\]

d) \( H_w = 1.38 \times 1 \text{ from } fig. 61 \text{ in } 3.424 \text{ (wes)} \)

e) \( h_e = H_a - H_w = 4.22 - 1.38 = 2.84 \)

f) \( \Theta_w = h_e + 4.24(0.03471) = 81.62/a \)

\[
\begin{array}{c|c|c|c|c}
\hline
a & a/2 & \% & \Theta_w & \Theta_m \\
\hline
60 & 60 & 1.50 & 0.50 & \\
75 & 75 & 1.44 & 0.58 & \\
90 & 90 & 1.30 & 0.90 & \\
100 & 100 & 1.00 & 0.82 & \\
\hline
\end{array}
\]

h) By inspection \( \Theta_w = 0.90 \) and \( a = 90 + 10 \times (\% ) = 91 \text{ ft} \)

i) \( \Theta_m \) from fig. 60 using \( y_{H_w} = 91, \ D / a = 0.0091 = 1.19 \)

\( \Theta_m = 0.96 \)

j) \( \Theta_w = 0.90 \times \Theta_m = 0.96 \) proceed with steps k. to m)

k) \( H_m = h_e = 4.22 \text{ ft; } \Delta M = 0.03471 \text{ from h) above} \)

Assume \( a = 91 \text{ ft} \); \( Q_a = 14.72 \times \Delta M \times 4 \text{ D} \)

\[
= 14.72 \times (91) \times (0.03471) \times (10^8) = 753.9 \text{ ppm}
\]

l) \( H_w = 1.75 \text{ ft from fig. 60} \)

m) \( h_m = H_m - H_w = 4.22 - 1.75 = 2.47 \text{ ft} \)
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 7 by RWC

Relief well analysis (cm³)

\[ P = 0.50 \ (cm³) \]

a) \[ h_\text{av} = h_\text{m} \left( \frac{\Theta_\text{av}}{\Theta_\text{m}} \right) = 2.47 \left( \frac{0.90}{0.91} \right) = 2.32 \]
b) \[ h_\text{av} + h_\text{w} = 2.32 + 1.75 = 4.07 \]
c) \[ \Delta M = \frac{H - h_\text{av} - h_\text{av}}{\xi} = \frac{12.3 - 4.07}{364} = 0.03565 \]
d) \[ \Delta M = \frac{h_\text{m} / h_\text{av}}{\xi} = 2.47 \left( \frac{0.03565}{0.91} \right) = 69.29 \%
\begin{tabular}{l|c|c|c}
\hline
\( a \) & \( \Theta_\text{m} \) \\
\hline
70 & 0.99 \\
80 & 0.87 \\
90 & 0.77 \\
\hline
\end{tabular}

\[ \Theta_\text{m} \text{ from fig. 60} \]

<table>
<thead>
<tr>
<th>( a )</th>
<th>( 10/h_\text{w} )</th>
<th>( D/\xi )</th>
<th>( \Theta_\text{m} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>70</td>
<td>1.54</td>
<td>0.89</td>
</tr>
<tr>
<td>80</td>
<td>80</td>
<td>1.35</td>
<td>0.83</td>
</tr>
<tr>
<td>90</td>
<td>90</td>
<td>1.20</td>
<td>0.85</td>
</tr>
</tbody>
</table>

\[ \Theta_\text{m} \text{ by inspection} \]
\[ \Theta_\text{m} = 0.91 \quad a = 70 + 10(\frac{8}{2}) = 77 \text{ ft (2nd trial well spacing)} \]

\[ \Theta_\text{av} \text{ from fig. 60} \]
\[ 10/h_\text{w} = 77, D/\xi = 1.40, \Theta_\text{av} = 0.88 \]

m) Repeat steps k) to t) using \( \Theta_\text{av} = 0.88, \Theta_\text{m} = 0.91 \)

k) \[ h_\text{m} = h_\text{w} = 4.22, \Delta M = 0.03471 \text{ (from b) above)} \]
\[ \Theta_\text{w} = 14.72 \frac{\Delta M}{D} \]
\[ = 14.72 \left( \frac{0.03471}{0.15} \right) = 4.57 \text{ gpm} \]

l) \[ h_\text{w} = 1.40 \text{ ft (from fig. 61)} \]

m) \[ h_\text{m} = h_\text{m} - h_\text{w} = 4.22 - 1.40 = 2.82 \text{ ft} \]

n) \[ h_\text{av} = h_\text{m} \left( \frac{\Theta_\text{av}}{\Theta_\text{m}} \right) = 2.82 \left( \frac{0.88}{0.91} \right) = 2.73 \text{ ft} \]

o) \[ h_\text{av} = h_\text{w} + h_\text{w} = 2.73 + 1.40 = 4.13 \text{ ft} \]

p) \[ \Delta M = \frac{H - h_\text{av} - h_\text{w}}{\xi} = \frac{21.3 - 4.13}{364} = 0.0213 \]

E192
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 7 by KWC
Kelvin well analysis \((\text{cm}^3)\)

\(P = 0.50 \ (\text{cm}^3)\)

1. \(\Theta_m = \frac{h_m}{\Delta M} = \frac{2.62}{a} (0.03527) = 79.95\%\)

2. \(\alpha\) from fig. 6a

<table>
<thead>
<tr>
<th>(a)</th>
<th>(%)</th>
<th>(%)</th>
<th>(\Theta_m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>70</td>
<td>1.54</td>
<td>0.89</td>
</tr>
<tr>
<td>80</td>
<td>80</td>
<td>1.35</td>
<td>0.72</td>
</tr>
<tr>
<td>90</td>
<td>90</td>
<td>1.10</td>
<td>0.94</td>
</tr>
</tbody>
</table>

3. By inspection \(\Theta_m = 0.93\) and \(a = 80 + 10 (\frac{\Theta_m}{10}) = 86\ ft\)

3d trial well spacing = 86 ft

4. \(\Theta_m\) from fig. 6b; \(a/\alpha = 86\); \(B/a = 1.26\); \(\Theta_M = 0.90\)

5. Repeat steps 2) to 3) using \(a = 86\)

\(\Theta_M = 0.90\)

\(\Theta_m = 0.93\)

6. \(Q_M = 4.22\), \(\Delta M = 0.03471\) (from 1b) above

\(Q_m = 14.72\) \(a = 86\) \(\Delta M = D\)

\(= 14.72 \cdot (86/0.03471) \cdot (0.15) \cdot (108) = 712.9\ \text{gpm}\)

7. \(H_M = 1.64\) ft (from fig. 6a)

8. \(h_m = H_m - H_w = 4.22 - 1.64 = 2.58\) ft

9. \(h_m = h_m (\Theta_m/\Theta_m) = 2.58 (0.93/0.93) = 2.54\) ft

10. \(H_w = h_m + H_w = 2.54 + 1.60 = 4.14\) ft

11. \(\Delta M = \frac{4 - H_w - H_{\text{ex}}}{5} = \frac{22.3 - 4.14 - 4.14}{5} = 0.03521\)

12. \(\Theta_m = \frac{h_m}{\Delta M} = 2.62/\Delta M = 74.41\%\)

<table>
<thead>
<tr>
<th>(\alpha)</th>
<th>(\Theta_m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>1.04</td>
</tr>
<tr>
<td>80</td>
<td>0.93</td>
</tr>
<tr>
<td>90</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Levee Underseepage Computer Program

Hand Computations used for Verification
Cross Section No. 7 by LWC

Relief Well Analysis (cont.)

P = 0.50 (cont.)

2.3) \( \Theta_m \) from fig. 60

<table>
<thead>
<tr>
<th>a</th>
<th>( \sigma/W )</th>
<th>( b/c )</th>
<th>( \Theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>70</td>
<td>1.54</td>
<td>0.89</td>
</tr>
<tr>
<td>50</td>
<td>80</td>
<td>1.35</td>
<td>0.92</td>
</tr>
<tr>
<td>90</td>
<td>90</td>
<td>1.33</td>
<td>0.94</td>
</tr>
</tbody>
</table>

5.8) By inspection \( \Theta_m = 0.92 \) and \( a = 80 + 10(1/0) = 81 \) ft

4th trial well spacing = 81 ft

7.5) \( \Theta_{aw} \) from fig. 60; \( a/\sigma = 81, b/c = 1.05 \) \( \Theta_{aw} = 0.90 \)

8.5) Repeat steps 6) to 7) using \( a = 81 \)

\( \Theta_{aw} = 0.90 \)

\( \Theta_m = 0.92 \)

9.4) \( \text{HW} = \text{HW} = 4.22 \) ft, \( \Delta M = 0.03471 \) from 6) above

\( \text{QM} = 14.72 \) and \( \Delta M = 0.03508 \)

10.4) \( \text{HW} = 1.50 \) ft from fig. 60

11.4) \( \text{km} = \text{HW} - \Delta M = 4.22 - 1.50 = 2.72 \) ft

12.4) \( \text{HW} = \text{HW} + \text{HW} = 2.16 + 1.50 = 4.16 \) ft

13.4) \( \Delta M = \frac{4 \cdot \text{HW}}{5} - \frac{\text{HW}}{3} = \frac{22.2 - 4.14}{364} = \frac{18.06}{262} = 0.03508 \)

14.4) \( \Theta_m = \frac{\text{km}}{\Delta M} = 2.72 / (0.03508) = 77.53 \)

<table>
<thead>
<tr>
<th>a</th>
<th>( \sigma/W )</th>
<th>( b/c )</th>
<th>( \Theta_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>70</td>
<td>1.54</td>
<td>0.89</td>
</tr>
<tr>
<td>80</td>
<td>80</td>
<td>1.36</td>
<td>0.92</td>
</tr>
<tr>
<td>90</td>
<td>90</td>
<td>1.20</td>
<td>0.94</td>
</tr>
</tbody>
</table>
Levee Underseepage Computer Program

Hand Computations used for Verification

Cross Section No. 7 by RMS

Date 8/24/67
Page 14 of 14

Relief Well analysis (cont'd)

(P = 0.50 (cont'd)

By inspection \( \Theta_m = 0.93 \) and \( a = 80 + 10 \left( \frac{4}{3} \right) = 84 \frac{1}{3} \).

Compare 84.5 ft with 4th trial well spacing 81 ft.

Close enough, use \( a_{cel} = 81 \) ft.

\( Q_w = 14.72 \text{ ft} \cdot \text{cm}^2 \cdot \text{D} \)

\[ = 14.72 \times (81) \times (0.03508) \times (10^5) = 6.78 \times 10^8 \text{ gpm} \]

Cost per well (plastic pipe and screen):

\[ C_w = (D \times R_p + R_p) \times \frac{Z}{2} + (D \times P_p + W + F) \times \frac{W}{2} + B + F + W + C + W \]

\[ = (20 + 30) \times 7.4 + (16 + 5 + 12) \times 10^8 \times 10^5 + 400 + 300 + 1000 \]

\[ = \$8172 \text{ / well} \]

Cost per 100 ft of levee station:

\[ C_{100} = C_w \times \frac{100}{a_{cel}} = 8172 \times \frac{100}{81} = \$10,090 \text{ /100 ft} \]

E195
PROJECT NAME: PROGRAM DEVELOPMENT  
STATION: X-SECT. 7

GENERAL CONTROL MEASURE INPUT DATA

---

LTE = 453.7 FT
H = 22.3 FT
LTO = 0 FT  RTO = 180 FT
L1 = 200 FT  ENTRANCE = OPEN
L3 = INFINITE FT  EXIT = INFINITE
D = 108 FT  DD = 108 FT
ZBL = 7.4 FT  KBL = .0015 CM/S
ZBR = 6.9 FT  KBR = .00075 CM/S
ZT = 7.4 FT  KF = .15 CM/S
ZL = 7.4 FT

SUBWT = 53 LB/CU FT

SUPPLEMENTAL CONTROL MEASURE INPUT DATA

---

BERM

FSB = UNDEFINED
I0B = .34
I1 = 0.8
M1 = .26
M3B = .20

RIVERSIDE BLANKET

IA = 0.7
M3R = .20
M4 = .25

CUTOFF

NO SPECIAL INPUT REQUIRED

FSW = 1.5
IOW = .566
RW = 1.0 FT
DP = 0.67 FT
RUUF = .0001
VISCOS = 0.0000121 GAL*FT/SEC
J = UNDEFINED %
HEL = 0.33 FT
PROJECT NAME: PROGRAM DEVELOPMENT  
STATION: X-SECT. 7  

LEVSEE UNDERSEEPAGE ANALYSIS  
INITIAL CONDITIONS  

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>X1</td>
<td>184. FT</td>
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<tr>
<td>X3</td>
<td>283. FT</td>
</tr>
<tr>
<td>M</td>
<td>3449E-01</td>
</tr>
<tr>
<td>I</td>
<td>1.318</td>
</tr>
<tr>
<td>QS</td>
<td>823. GPM/100 FT</td>
</tr>
<tr>
<td>H0</td>
<td>9.8 FT</td>
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<tr>
<td>$</td>
<td>1.1670</td>
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PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 7

OUTPUT DATA FOR BERM ANALYSIS

ROCK ISLAND BERM

\[ X_1 = 184. \text{ FT} \]
\[ X_3 = \text{UNDEFINED} \]
\[ M = \text{UNDEFINED} \]
\[ I = \text{UNDEFINED} \]
\[ Q_s = \text{UNDEFINED} \]

\[ X_{RI} = 43. \text{ FT} \]
\[ T = 3.1 \text{ FT} \]
\[ V_B = 522. \text{ CU YD/100 FT LEVEE STATION} \]

BERM COST CALCULATION

ROCK ISLAND BERM

\[ V_B = 522. \text{ CU YD/100 FT LEVEE STATION} \]
\[ \text{UNIT COST} = \$ \quad 3.75 /\text{CU YD} \]
\[ \text{TOTAL COST} = \$ \quad 1958.00 /100 \text{ FT LEVEE STATION} \]
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 7

OUTPUT DATA FOR BERM ANALYSIS

--- Hand Calculations ---

SAND BERM

X1 = 184. FT
X3 = UNDEFINED
M = UNDEFINED
I = UNDEFINED
D3 = UNDEFINED

XS = 177. FT
T = 7.5 FT
VB = 3448. CU YD/100 FT LEVEE STATION

--- BERM COST CALCULATION ---

SAND BERM

VB = 3448. CU YD/100 FT LEVEE STATION
UNIT COST = $ 3.75 /CU YD
TOTAL COST = $ 12929.00 /100 FT LEVEE STATION

12,750
RIVERSIDE BLANKET ANALYSIS

---

XR = 754. FT  
L1 = 200. FT

IF XR OR L1 > DISTANCE TO RIVER, SOLUTION INFEASIBLE

DO YOU WANT TO CONTINUE? (Y/N) N

PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 7
PROJECT: PROGRAM DEVELOPMENT
STATION: X-SECT. 7

OUTPUT DATA FOR CUTOFF ANALYSIS

\[ \frac{DC}{D} = 0.950 \]

\[ X_1 = 184. \text{ FT} \]
\[ X_3 = 283. \text{ FT} \]
\[ M = 0.2907 \times 10^{-1} \]
\[ I = 1.023 \]
\[ Q_s = 489. \text{ GPM/100 FT} \]

CUTOFF COST CALCULATION

\[ \text{DEPTH} = 110. \text{ FT} \]
\[ \text{COST} = \$ 55,500.00 /100 \text{ FT OF LEVEE STATION} \]

Hand Calculations

\[ 4.89 \]
**OUTPUT DATA FOR RELIEF WELL ANALYSIS**

<table>
<thead>
<tr>
<th>P</th>
<th>ASEL</th>
<th>WBAR</th>
<th>QW</th>
<th>COST</th>
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<tbody>
<tr>
<td>.250</td>
<td>58.4</td>
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<td>$12484.00</td>
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<tr>
<td>1.000</td>
<td>106.</td>
<td>108.</td>
<td>847.</td>
<td>$13482.00</td>
</tr>
</tbody>
</table>

.250 | 58. | 27. | 359. | $8877.00 <= Minimum Cost