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Guide for Mechanistic-Empirical Design
OF NEW AND REHABILITATED PAVEMENT STRUCTURES

FINAL DOCUMENT

APPENDIX TT: DRAINAGE REQUIREMENT IN PAVEMENTS (DRIP) MICROCOMPUTER PROGRAM USER'S GUIDE

NCHRP

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
National Research Council

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February 2004

Foreword

The contents of this appendix were adapted from the FHWA DRIP User's Guide (1) and are provided in support of PART 3, Chapter 1 and Appendix SS of the Design Guide. DRIP can be used to perform the necessary calculations for the hydraulic design of permeable bases and edgedrains, as well as for the design of aggregate and geotextile separator layers. This program is available in the Design Guide software under the Tools/Additional Programs menu.

Acknowledgements

Applied Research Associates, Inc., developed the original version of the microcomputer program titled "Drainage Requirements in Pavements (DRIP) Version 1.0" under a contract from the FHWA (contract No. DTFH61-95-C-00008). Mr. Robert Baumgardner of the FHWA supplied technical control for the project. The ARA principal investigator was Dr. Walter Barker, and Mr. Tim Wyatt led the development of the computer program. Dr. Jim Hall served as program manager. The program was delivered to the FHWA in September 1997.

This program was modified and enhanced by the ERES Division of ARA under FHWA Contract No. DTFH61-00-F-00199). Mr. Robert Baumgardner and Mr. Bing Wong of the FHWA supplied the technical control for the project. The ERES principal investigator was Dr. Jim Hall, and Mr. Gregg Larson implemented the program modifications. Mr. Jagannath Mallela of ARA-ERES served as the project manager. Under this contract, DRIP Version 2.0 and a revised user's guide were developed.

Incorporation of DRIP into the design guide was done at ARA-ERES under the guidance of Mr. Jagannath Mallela.

APPENDIX TT: DRAINAGE REQUIREMENT IN PAVEMENTS (DRIP) MICROCOMPUTER PROGRAM USER'S GUIDE

1.0 INTRODUCTION

Brief History of DRIP Development

Moisture-related pavement distresses have long been recognized as a primary contributor to premature failures and accelerated pavement deterioration. The Federal Highway Administration (FHWA) provides design guidance for drainage in its manual numbered FHWA-TS-80-224, "Highway Subdrainage Design." Under a study known as Demonstration Project No. 87, or simply "Demo 87," the FHWA Pavement Division developed a comprehensive effort to provide design guidance for handling water that infiltrated into the pavement structure from the surface. That study resulted in the production of the Participant Notebook for Demonstration Project No. 87. Engineers needed a concise and user-friendly microcomputer program that replicates the subsurface drainage design procedures in the Participant's Workbook for Demonstration Project No. 87. Also, because of the increasing use of the SI unit system, there was a need for the program to incorporate both SI and pound-inch (U.S. Customary) units.

Under a contract from the FHWA (contract No. DTFH61-95-C-00008) Applied Research Associates, Inc., developed the original version of the microcomputer program titled "Drainage Requirements in Pavements (DRIP) Version 1.0." DRIP was finalized in 1997.

In 1998, a new National Highway Institute course (NHI Course No. 131026) titled "Pavement Subsurface Drainage Design" was developed to further improve the guidance on pavement subsurface drainage design, construction, and maintenance. DRIP Version 1.0 was integrated into this course to perform hydraulic design computations. The program has since been used in the industry and has received excellent reviews.

However, several valuable suggestions were made by DRIP users to further improve the program. The suggestions mainly pertained to improving design input screen graphics, variable plot displays and outputs, and the user's manual. Certain key drainage calculations and plotting options were also suggested to enhance DRIP's technical capabilities. In addition, there was a need to upgrade the program to be compatible with the computing environments prevalent today.

Thus version 1.0 of the program was modified and enhanced by the ERES Division of ARA under FHWA Contract No. DTFH61-00-F-00199). The enhanced version 2.0 was finalized in 2000.

DRIP Capabilities

The salient features of DRIP are described below. Each of these features can be executed independently from within the program.

Roadway Geometry Calculations

Using this program feature, the user can compute the length and slope of the true drainage path based on the longitudinal and transverse grade of the roadway, as well as the width of the underlying base material. The user can perform these calculations for the two common roadway cross-sections commonly encountered—crowned and superelevated (uniform slope) sections.

Sieve Analysis Calculations

The effective grain sizes (D_x), total and effective porosities, coefficient of uniformity and gradation, and coefficient of permeability can be computed for any user-entered gradation using this program feature. Plots of the gradations on semi-log and FHWA power 45 templates can also be obtained from this program screen.

Inflow Calculations

The amount of moisture infiltrating the pavement structure from rainfall and meltwater can be computed using this program option. The surface infiltration calculations can be performed using two different approaches—the Infiltration Ratio approach and the Crack Infiltration approach. Meltwater computations can be performed for a variety of soil types and pavement cross-section depths.

Permeable Base Design

The program offers two permeable base design options—depth-of-flow and time-to-drain. These methods allow the user to design an open-graded base that can handle the inflow entering the pavement structure.

Separator Layer Design

Using this program option, the user can design two types of separator layers—geotextile and aggregate separator layers. Based on the gradations of the proposed permeable base and the subgrade under consideration, the program also verifies whether a separation layer is required at all.

Edgedrain Design

Two types of edgedrains can be designed using this program option—geocomposite of fin drains and pipe edgedrains. The program calculates the edgedrain capacity and the outlet spacing required.

New Features in DRIP Version 2.0

DRIP 2.0 retains the capabilities of the earlier version of the program but makes the execution more efficient and incorporates all the new features explained in the previous section. DRIP 2.0 incorporates several significant advancements in user interface and capabilities:

- *Win32 support*. Fully compatible with Windows 95/98/NT.
- *Normal and Expert modes*. Normal mode warns users of potential errors during input and offers suggestions on proper program use. Expert mode suppresses these warnings, allowing experienced users of program the ability to edit data more quickly, without continually acknowledging warning screens.
- *Tabbed property pages*. The individual data input and analysis screens employed in DRIP Version 1.0 have been updated/improved and are now displayed using a property page format. This new format allows a more intuitive navigation through the various program screens. Each property page can be accessed by means of the tabs displayed continually along the top of the DRIP client area.
- *Analysis type selection*. The DRIP program allows the user to select the type of roadway geometry, inflow calculation method, permeable base analysis type, separator layer analysis type, and edgedrain type. The selections available under each of these categories are usually located in the upper left corner of the respective property page in the form of radio buttons. By making the appropriate selection, the user can customize the analysis performed on each property page. For example, to perform time-to-drain design of permeable bases, the user should select the "Time to Drain" radio button on the ***Permeable Base*** property page. The program then configures the page to display appropriate inputs and outputs for this analysis.
- *Hyper-linked input data fields*. In the DRIP program, certain variables appear on multiple property pages. The hyper-linking feature is aimed at preventing the novice user from inadvertently entering different values for the same DRIP variable on different property pages. By clicking the left mouse button on a hyper-linked variable (identified by an underline beneath it), the program transports the user to a property page where this variable should most logically be configured.
- *Improved graphics*. The graphics that illustrate drainage input variables have been improved.
- *Summary screen*. A linked summary list is now present on the left side of the DRIP client window. This list allows the user to get an update on the status of the current DRIP session.

- *Context sensitive help*. Right clicking on any variable in the DRIP program displays a short description of that variable.
- *Improved online help*. The complete DRIP user's manual is now available and searchable online and from within the program.
- *HTML analysis summary*. A formatted report on the inputs used and outputs calculated in the current DRIP session is available using the File | Export Summary command. This information contained in this file is in standard HTML format and can be read and edited using standard browser applications, word processing programs, or spreadsheet software.
- *Print analysis summary*. A well-formatted printed report displaying the inputs used and outputs calculated in the current DRIP session is available using the File | Print Summary command.
- *Improved gradation library*. The importing and saving of sieve gradation analysis has been improved. The program allows descriptive file naming to save input gradations for future use.
- *Additional sieve sizes*. Particle sizes determined from hydrometer tests can now by used by the DRIP model.
- *Improved graphing*. Graphing of grain size distributions and sensitivity analysis plots has been simplified. Graphs generated by DRIP can now be imported directly into other Windows® applications or saved as JPEG files.
- *Power 0.45 and semi-log plots*. Sieve analyses can be viewed on either power 0.45 or semi-log plots.

2.0 ORGANIZATION OF THIS APPENDIX

This appendix is organized so that both the novice and experienced DRIP users can navigate easily through the program's many different features. The content of this manual is also available with the program as online help. In an effort to minimize repetition, topics that are identical in different parts of the program are usually only covered once in detail; when repeated, the reader is referred to previous explanations.

Getting Started

In Getting Started, the user will learn about the minimum system requirements for running DRIP 2.0 on a personal computer or network, DRIP 2.0 installation, and the usage of DRIP 2.0 to perform pavement drainage analysis and design.

General DRIP Operation

This section provides an in-depth guide on how to use DRIP 2.0, including file handling, data input, data analysis, and report generation. Operation of the DRIP plotting package—DripPlot—is also fully described.

Examples Problems

This section provides example problems to assist the user in developing a proficiency in the use of the program.

Sensitivity Analysis

This section discusses the design sensitivity to changes in various parameters, which can be used both as a design reference and as an example of the type of detailed analyses that can be performed using the DRIP program.

3.0 GETTING STARTED

Getting started with DRIP 2.0 is easy, especially if you already have installed the Design Guide software program. To install DRIP, go to the *Tools/Additional Programs* menu on the menu selection tool bar in the Design Guide software, and select the DRIP icon. This action will install the program automatically. Once installed, the program can be accessed from within the Design Guide software using the same menu selections.

System Requirements

To run DRIP 2.0 on your computer, the following minimum hardware and software requirements must be met:

- IBM-compatible PC with at least a Pentium processor.
- 32 MB of RAM.
- 15 MB of available hard disk space.
- One CD-ROM drive (for installation only).
- Monitor capable of 800x600 resolution.
- Mouse or compatible pointing device.
- Printer (optional).

Also, the computer on which DRIP 2.0 is installed must be running Microsoft Windows 95/98 or Windows NT 4.0 operating system (or a compatible later version).

Basically, if all the requirements to run the Design Guide software are satisfied, then the system requirements for DRIP 2.0 will be satisfied.

4.0 GENERAL DRIP OPERATION

When the user starts the DRIP program, a splash screen appears briefly, followed by the DRIP client window shown in Figure 1. The DRIP client window has the following features:

- A menu bar across the top, which includes the File menu, the Options menu, and the Help menu.
- A program summary column on the left side of the screen that displays all the important DRIP outputs. The summary information is continually updated as the analysis progresses.
- A series of six tabs arranged from the left to right titled ***Roadway Geometry***, ***Sieve Analysis***, ***Inflow***, ***Permeable Base***, ***Separator***, and ***Edgedrain***. When selected, these tabs display the respective property pages. Each property page has the following common elements: edit boxes for data input, on-screen graphics describing the problem, and calculator and/or graph icons for output computation. In addition, some property pages have module-specific analysis options, e.g., the ***Edgedrain*** property page allows the user to choose between pipe edgedrain or geocomposite edgedrain analysis types. All the hydraulic design and analysis in DRIP takes place within these property pages.

DRIP has many features that can be used from anywhere within the program. These include file or project actions such as saving and printing, as well as the functions of certain function keys, and on-screen buttons. This chapter describes many such features that are available throughout the program. In addition, a detailed description of the functionality of each tabbed property page is also provided. The description of the DRIP program features and operation is broken down and presented under the following section headings:

- General DRIP features – DRIP icons, context sensitive help, hyper-linking, error checking.
- DRIP Menus – File handling, Help, and Options.
- DripPlot – Graphing and plotting package for DRIP.
- DRIP Property Pages – Tabbed property pages each containing one of the six sub-processes required for a complete drainage analysis.
- Project Summary – Summary of important input and output data for the program.

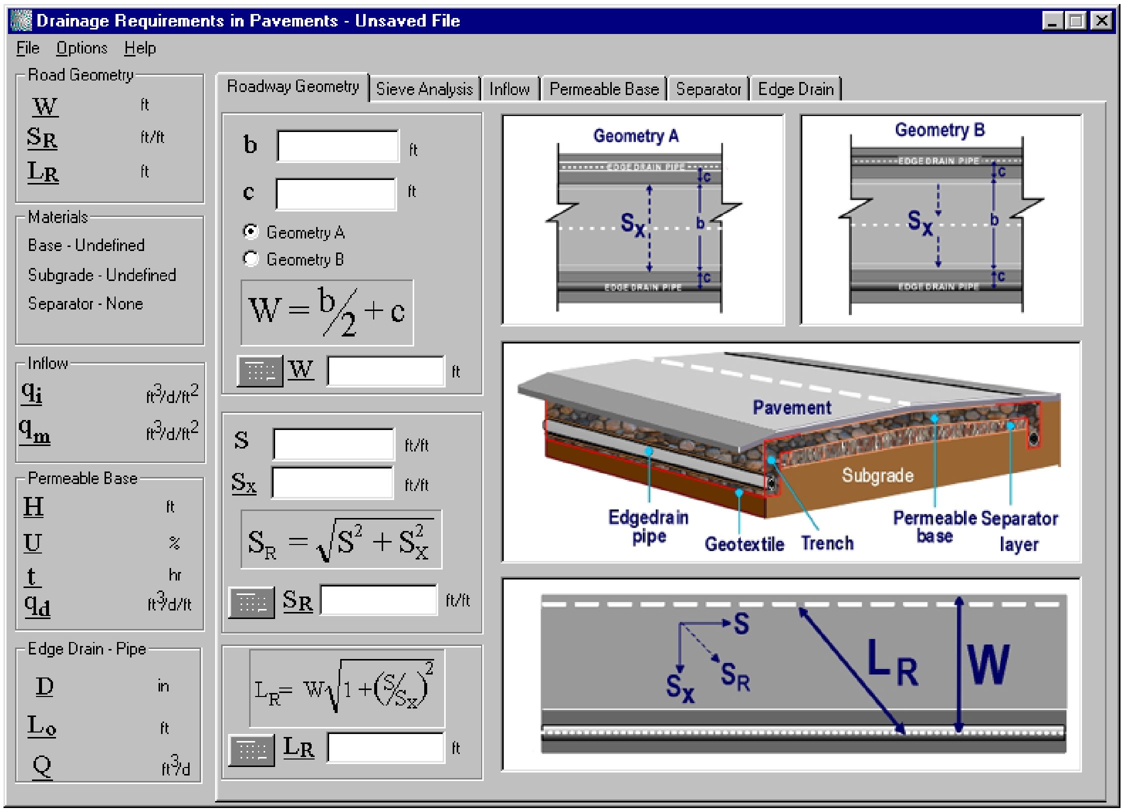


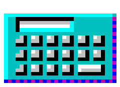
Figure 1. The DRIP client window.

General DRIP Features

DRIP has many features to assist the user in operating the program, including special icons, context sensitive help, hyper-linking of variables, and input data error checking.

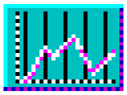
<u>DRIP Icons</u>

There are three of types of icon buttons in DRIP – Calculator, Graph, and Balance. The icons are illustrated and explained below.

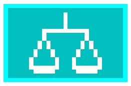


Calculator icon: Allows the user to perform a calculation based on the inputs provided by the user. This icon is activated (turns colorful) only when all the necessary inputs for a given calculation are configured. For example, in Figure 1, the parameter *W* can be calculated by pressing the calculator icon only after the inputs *b* and *c* have been configured. In certain instances, pressing the calculator icon opens a dialog box (e.g., heave rate determination in the ***Inflow*** property page), or transports the user to an appropriate property page where inputs to calculate the parameter under question should be configured (e.g., the D_x calculation in the

Separator property page). Calculator icons appear on every property page.



Graph icon: Generates appropriate graphs for the property page in which it is located and opens DripPlot to display them. The graph icons appear on ***Sieve Analysis***, ***Permeable Base***, and ***Separator*** property pages.



Balance icon: Checks whether the design criteria for the aggregate and geotextile separator layers are satisfied on the ***Separator*** property page.

DRIP Help

Context-sensitive help can be accessed for any program variable by right-clicking the mouse button while the cursor is on top of that variable. A small help box will appear superimposed above the DRIP dialog box, giving a short description of the variable in question.

Hyperlinking in DRIP

Most of the property pages in DRIP are interconnected. As a consequence an input on a certain page may be an output on another page. Therefore, a given variable can appear on multiple property pages. For example the parameter, *W*, appears on both the ***Roadway Geometry*** and ***Inflow*** property pages. However, it is actually an output on the ***Roadway Geometry*** property page and an input in the ***Inflow*** property page. This could lead to some confusion in the mind of the novice user on where to enter the value for parameter *W*. In order to address such situations, a hyperlink was provided for all variables that appear on multiple screens. All hyperlinked variables are identified by an underline beneath them. If a hyper-linked variable is selected with a left-click of the mouse, the program will jump to where that variable should most logically be entered. By editing the variable on the analysis page suggested by DRIP, the user can avoid inadvertently entering different values for the same variable on different screens. Although the user is not required to use this feature, it is highly recommended, especially for novice users and also when an analysis utilizing only a few of the property pages offered by the program is attempted.

Error Checking

DRIP displays a warning when a dependent variable is about to be changed. DRIP also warns the user when data input is inappropriate, such as entering a negative unit weight for a material. While this feature is helpful for a novice DRIP user, these warnings can become an annoyance for the experienced user. To aid the experienced DRIP user, an *Expert Mode* is available. When DRIP is running in the *Expert Mode* all warning and informational dialog boxes are suppressed, allowing the user to enter potentially incorrect data, or to edit a dependent variable. Only experienced users should attempt to use DRIP in the *Expert Mode*. The *Expert* or *Normal* mode selection is made under the *Options | Mode* menu item. When first run, DRIP defaults to the *Normal* mode, with all the warning and informational dialog boxes activated.

DRIP Menus

Menus in DRIP are used to control file handling, help, and program options. All menu items can be accessed from any of the tabbed property pages.

<u>File Menu Options (Including Print Summary)</u>

The *File* menu controls file handling, printing, and summary output. When DRIP is first started, the program opens into a new DRIP project or session file. This new DRIP file is empty except for a few default input parameters. At this time the user should either open a previously generated DRIP project file by using the *File | Open* menu command or name the newly created DRIP project file by using the *File | Save* menu command.

File | New – Creates a new DRIP project file, clearing all user input data from the currently active project file. There can only be one active project file for each DRIP client window. Creating a new DRIP project file with the *File | New* command within an active DRIP client will close the currently active DRIP file. A newly created DRIP project file is unnamed. It is suggested that the newly created DRIP project file be named using the *File| Save* menu command. While each DRIP client window allows only a single DRIP project file to be active, it is possible to have several DRIP client windows running on one computer.

File | Open – Opens a previously saved DRIP project file (identified by a *.drp extension). The current active DRIP project file is closed without saving. The *File | Open* dialog box is of the MS Windows Explorer® style, allowing the user to rename, copy, and paste files within it. Figure 2 illustrates the *File | Open* dialog box.

File | Save – Saves the current active DRIP project. When this option is selected, a dialog box, such as the one shown in Figure 3 opens prompting the user to save the current DRIP project. The user may choose to save a DRIP project with a file extension other than the default *.drp extension. However, this is not recommended since files saved with an alternative extension will not appear automatically in the dialog box when the *File | Open* menu command is executed. If the current active DRIP project has been previously saved, the *File | Save* menu command will not open the "Save generated DRIP data file" dialog box, but instead will overwrite the previously saved DRIP project file.

File | Save As – Same as *File | Save* menu command except that this command will always open the "Save generated DRIP data file" dialog box shown in Figure 3.

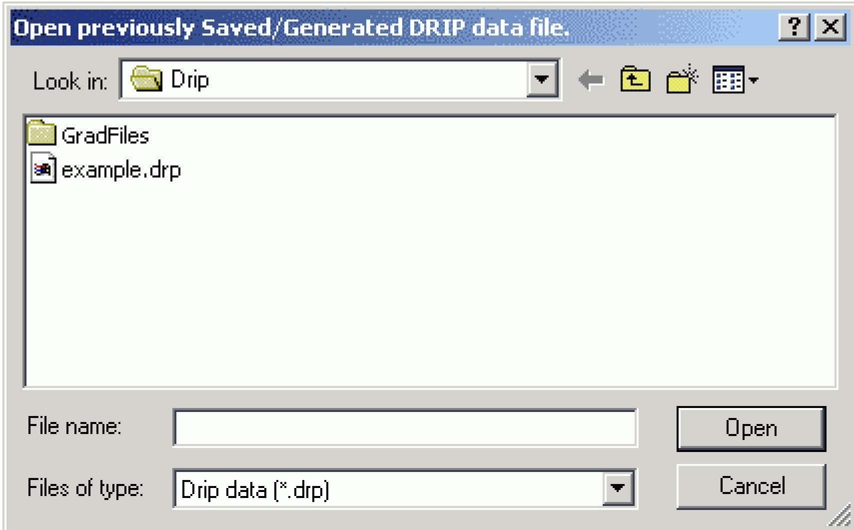


Figure 2. The file open dialog box.

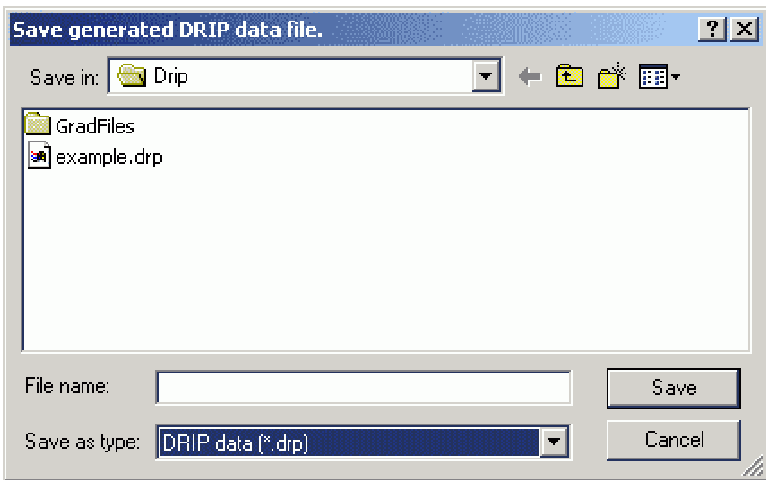


Figure 3. File save dialog box.

File | Export Summary – Creates a summary of the active DRIP project file. The format of this file is Hypertext Markup Language (HTML) and it can be viewed using any Web browser, spreadsheet, or word processing program. Since DRIP analyses are modular in nature, the summaries provided are also divided into subsections—Roadway Geometry, Sieve Analysis, Inflow, Permeable Base, Separator Layer, and Edge Drain. A summary for a particular subsection is output only if data has been entered for that analysis or that analysis has been completed. If no data has been entered, only the primary header of that analysis module is provided.

To export the project summary to an HTML file the following steps need to be followed:

1. Select the *File* | *Export Summary* command from the *File* menu. A "Create DRIP summary file" dialog box similar to the one shown in Figure 4 pops up prompting the user to enter to enter a file name under which the DRIP project file summary will be saved.
2. Save the summary file to an appropriate directory on the computer by specifying a file name. Note that the summary files are automatically saved with an extension of *.htm.

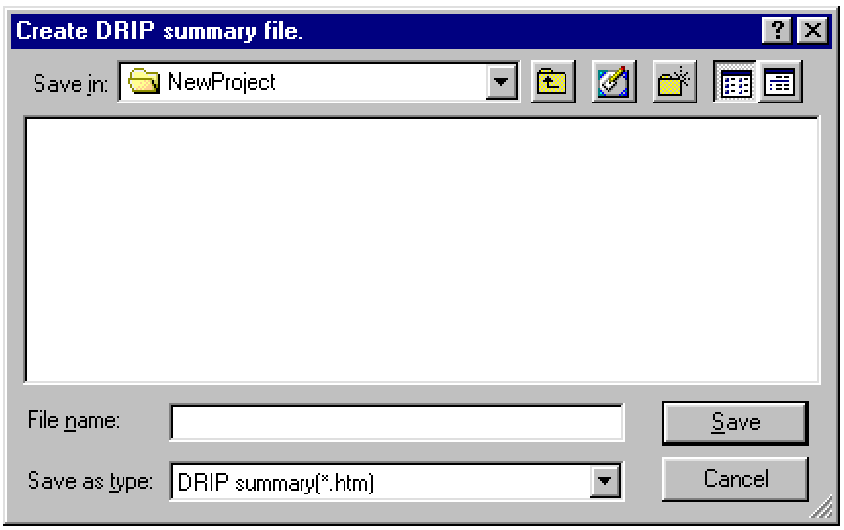


Figure 4. Dialog box to save project summary information.

Once the summary information is saved to a file, it is automatically displayed on the computer screen using the default HTML browser application. The information can be printed directly from this application using standard print commands. Alternatively, the summary information file can also be opened with any standard word processing or spreadsheet programs that reads HTML documents, e.g., Microsoft Word® or Microsoft Excel®. The advantage of using a word processing or spreadsheet application is that they enable the user to custom format the information contained in the file. Further, tabular data is stored using HTML tables, and therefore can be utilized directly by a spreadsheet applications such as Microsoft Excel® to create custom plots of DRIP data. This capability is in addition to the intrinsic plotting package (DripPlot) provided with DRIP.

File | *Print Summary* – Prints the output summary information. The following steps need to be followed to print the summary information.

1. Select the *File* | *Print Summary* command from the file menu. A "Create DRIP summary file" dialog box similar to the one shown in Figure 4 pops up prompting the user to enter a file name under which the DRIP project file summary will be saved.
2. The user can choose to either save the summary information to be printed to a file by clicking the *Save* button (recommended) or can opt not to save it by pressing

Cancel button. Note the summary files are automatically saved with an extension of *.htm.

3. After the file *Save* or *Cancel* operations are performed, the program automatically opens the "Print" dialog box shown in Figure 5 from where the user can select the printer to send the output to (the printer choices displayed will obviously be a function of the user's local environment).

Note that the output will be printed using default format settings. If the formatting of the default output layout needs to be changed, the user will need to open the saved summary file using standard word processing or spreadsheet programs to edit the file.

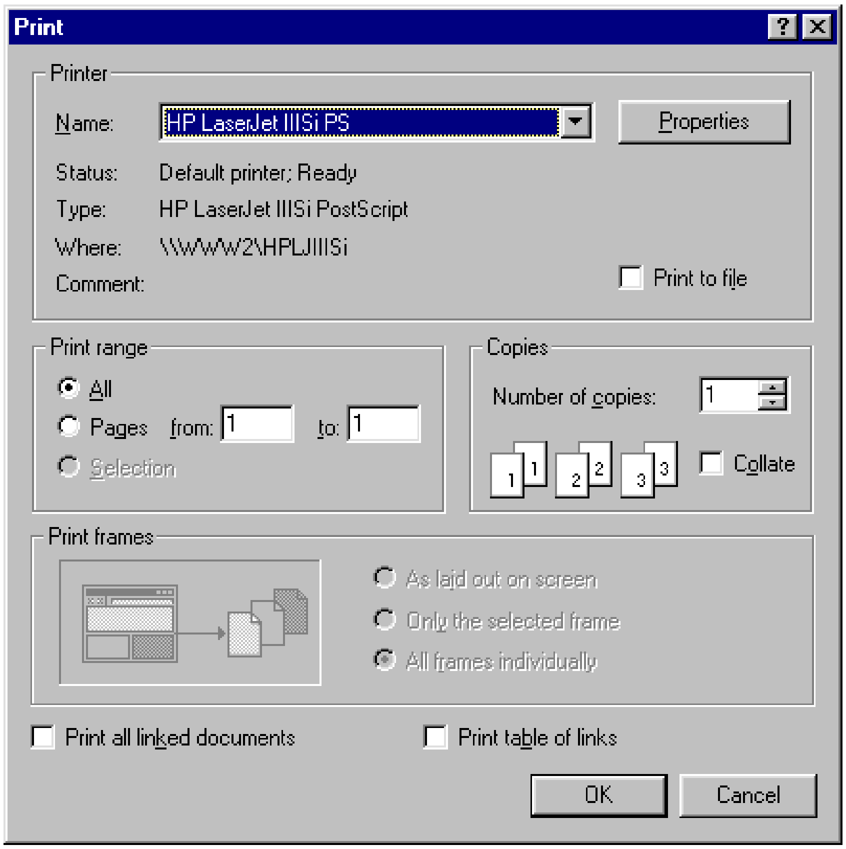


Figure 5. The Print dialog box.

File | Exit – Ends the current DRIP session. If the user selects this option or clicks on the Close icon on the client window, DRIP will generate a dialog box prompting the user to save the current project file. From here the user can choose to save the file, exit the program, or cancel the dialog box and return to the program. If the user chooses to save the file, the dialog box shown in Figure 3 will appear to facilitate data storage.

<u>Options Menu</u>

The *Options* menu sets the program options available in DRIP—Units, Mode, Sensitivity, and Plot Scale.

Options | Units – This menu command allows the user to toggle between metric and English standard units. All input and output variables in DRIP are converted when using the *Units* menu command. A checkmark appears next to the unit type in use. English units are used as default in DRIP.

Options | Mode – Determines the level of information and warning dialog boxes employed by DRIP. These dialog boxes inform the user when a program action or function deviates from those recommended by this manual. While this feature prevents the novice user of the program from making mistakes, it can become cumbersome for the experienced user. When the *Normal* menu item is checked, all warnings and information dialog boxes are displayed. The *Expert* mode suppresses all but the most important warning boxes, allowing the experienced user to make informed changes of input data, both dependent and independent. DRIP defaults to the *Normal* mode when started.

Options | Sensitivity – This option is specific to the Time to Drain and Depth of Flow analyses performed within the ***Permeable Base*** property page. It allows the user to determine which sensitivity analyses are to be performed during permeable base design. The choices are length, slope, permeability, inflow, drain (degree of drainage), thickness, and porosity. If any of these menu items is checked, a corresponding sensitivity analysis is performed during the permeable base design. DRIP defaults to performing sensitivity analysis for all appropriate input variables.

Options | Scale – Determines whether the horizontal scale of the sieve analysis plot is logarithmic or Power 0.45. If the former is chosen, logarithms of the sieve sizes are plotted against the percent passing to produce a semi-log plot. If the latter is chosen, the sieve sizes are raised to the 0.45 power and plotted against the percent passing to yield an FHWA power 0.45 chart. DRIP defaults to a power 0.45 scale for all gradation plots.

The semi-log plot is best used when plotting materials with large amounts passing the #200 sieve for which hydrometer analysis data is available. When these gradations are plotted on an FHWA power 0.45 chart, the plot is not as visually appealing. Semi-log plots are also useful when multiple gradations with widely differing sieve sizes are being plotted on the same chart, such as in aggregate separator layer design. An example comparison of a fine-grained material plotted using the Power 0.45 and semi-log scales is presented in Figure 6 and Figure 7. Note that the gradations used in both figures are identical. The advantage of using a semi-log plot scale for this gradation is obvious from these figures.

On the other hand, when plotting coarse-grained materials on a semi-log chart, the gradations have a tendency to fall within one or two logarithmic cycles, making the plot more difficult to read. The Power 0.45 scale is better for plotting coarse-grained materials.

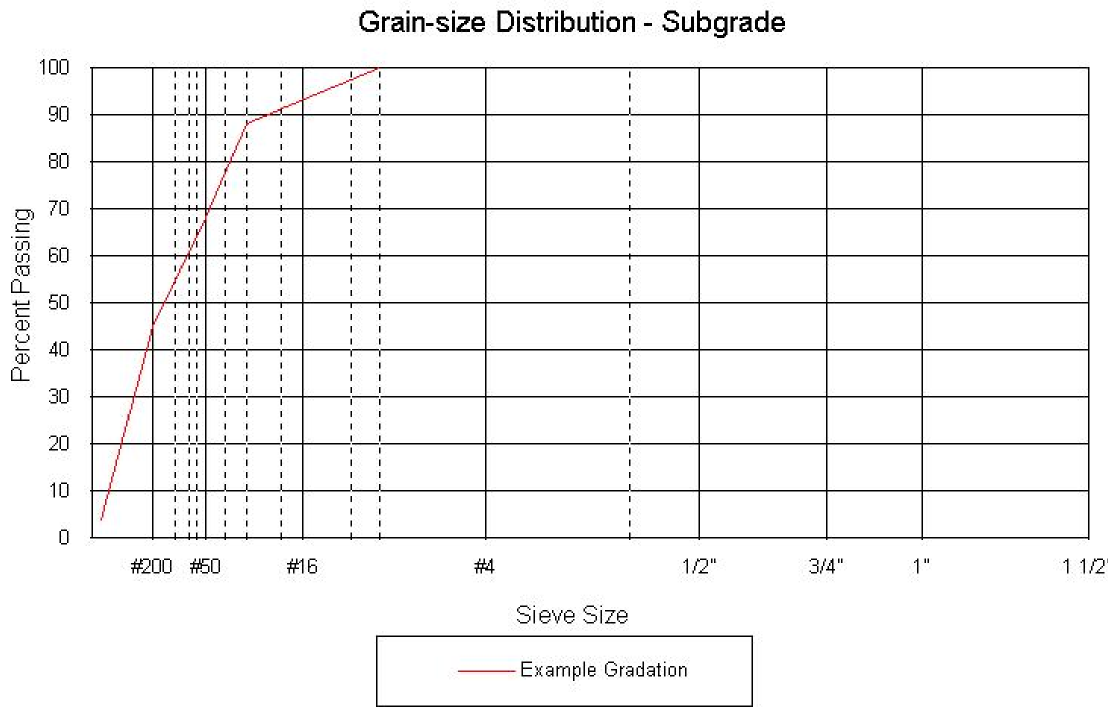


Figure 6. Sample subgrade gradation plot on FHWA power 0.45 chart.

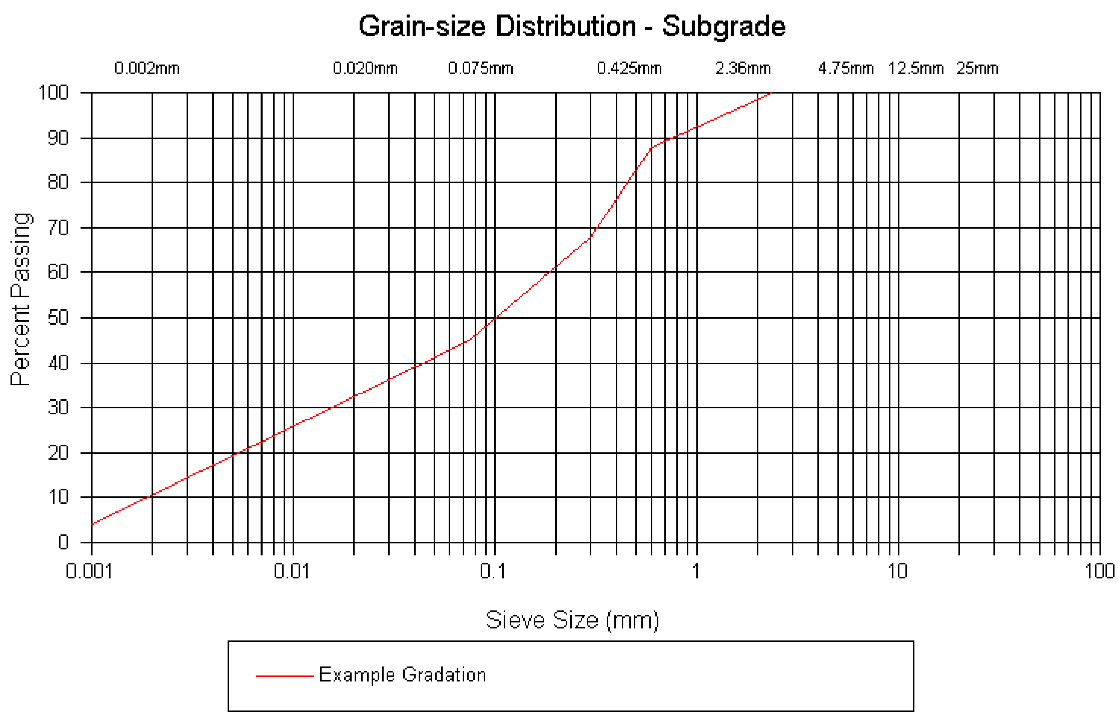


Figure 7. Sample subgrade gradation plot on a semi-log chart.

Help Menu

DRIP employs Windows HTML Help. The contents of this manual are available online and can be accessed by selecting the *Help | Contents* command from the menu. Context-sensitive help can be accessed from anywhere within the program by pressing the F1 function key. The DRIP HTML help is fully searchable by contents, index, or keyword. The contents of the help file can be printed directly using the standard print options provided.

DripPlot

DripPlot is a companion program to DRIP that creates plots of gradations, aggregate separator design, and sensitivity analysis for permeable bases. The information on the operation of DripPlot is provided below.

DripPlot does not contain file handling or data editing capabilities. Changes to the plotted data should be made using DRIP, and the results re-plotted with DripPlot. Once a plot is generated, the user may alter the plot's appearance. DripPlot allows the editing of titles, legends, font sizes, scales of the vertical and horizontal axes, line types, line colors, and line thicknesses.

Plots generated by DripPlot can be saved either as device independent bitmaps (*.dib) or as JPEG files (*.jpg). This allows the user to import data into other Windows programs for report preparation. The user may also copy a DripPlot graph using the *Copy* menu command or shortcut key (*control-C*) and paste the graph directly into any Windows program that allows cutting and pasting.

DripPlot Menus

The DripPlot menu contains several commands that are common to almost all Windows® applications. A short summary of these commands is included for completeness. Menu commands that are unique to DripPlot are discussed in detail.

File Menu

File | New – Opens another window with the currently plotted screens. This allows the user to have multiple windows of the same plot open. This feature is used primarily to view plots with differing scales, legends, titles, and so on.

File | Save as Dib File – Saves the current plot as a device independent bitmap. Saving a file as a *Dib* allows the user to import this plot into another Windows® application. The file is saved as it appears on the user's screen, including size, line color, and titles.

File | Save as Jpeg File – Save the current plot as a JPEG graphic file. Saving a file as a *Jpeg* allows the user to import this plot into another Windows® application. The file is saved as it appears on the user's screen, including size, line color, and titles.

File | Print – This menu command prints the current plot. By default, the plot is printed in portrait mode, with the margins set in *File | Print Page Setup*.

File | Print Preview – This command displays how each plot will look when printed.

File | Print Setup – Allows the user to select which printer to user, as well as edit that printer's properties such as paper source, paper size, and orientation.

File | Print Page Setup – Calls the Print Page Setup dialog box, which is shown in Figure 8. The dialog box sets the margins used when printing a DripPlot graph. Valid inputs in these boxes range from 0 to 100, and represent the distance from the top and left margins. For example, a value of 10% for the *Top Margin* means that the top margin will end 10% from the top of the page. A *Bottom Margin* of 60% means the bottom margin begins 60% from the top of the page. The net effect in this case is that the plot will take up 50% of the page.

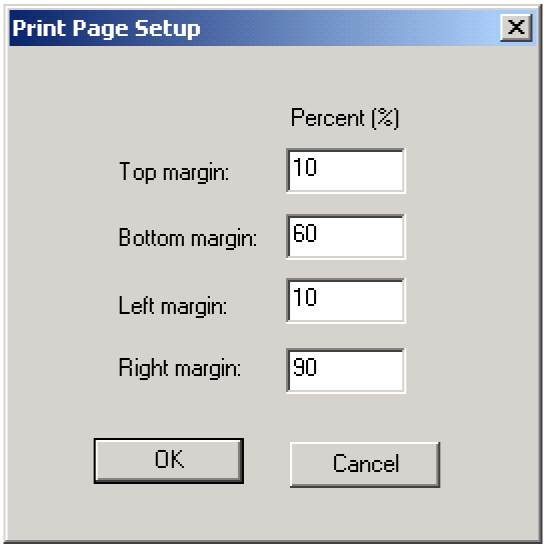


Figure 8. Print page setup.

Edit Menu

The *Edit* menu currently has a single menu command, which is *Copy*. The *Copy* command allows the user to copy the current plot onto the Windows® clipboard and to directly paste that plot into any applications that accept Windows® bitmaps.

View Menu

The *View* menu commands allow the user to change the basic look of the DripPlot application. *View | Toolbar* toggles whether the shortcut toolbar is displayed beneath the DripPlot menu. The *View | Status Bar* toggles whether the status bar is displayed along the bottom of the DripPlot Window. The status bar gives a short description of each menu item and displays whether the Num-lock, Cap-lock, and Scroll-lock keys are set.

<u>Window Menu</u>

The *Window* menu is designed to arrange and navigate among the plots generated by DRIP. At the bottom of this menu is a list of plot files currently open. Any plot can be brought to the foreground by selecting that plot name from among the menu options.

Window | New Window – Creates a new plot with current DRIP data. Used to recreate a modified plot.

Window | Cascade – Arranges plots one on top of the other, in a manner similar to that of a deck of playing cards. Each plot is slightly offset from the one directly above and below.

Window | Tile – Arranges plots side by side in the DripPlot window.

Window | Arrange Icon – Arranges minimized plots along the bottom of the DripPlot window.

<u>Chart Menu</u>

The *Chart* menu is used to modify the appearance of DRIP plots. DripPlot is designed to be a simple, straightforward plotting package. It is not completely customizable. If a user wishes to make highly customized plots, it is suggested that the information from DRIP be output using *File | Export Summary* to create an HTML summary file. This summary file can be imported directly into most standard graphing packages.

Chart | Titles and Labels – This command allows the user to edit the axis label and plot title text. The user can also change the font size of the all labels and titles. The "Titles and Labels" dialog box with sample graph and axes titles is shown in Figure 9. The default font sizes for the titles are also shown in the figure. Once the user is finished with entering the desired option values on this screen, the changes can be accepted by pressing the OK button.

Chart | Lines/Legends and Scale – This command allows the user to edit the legend labels and their font size, line color, line type, and line thickness. For graphs that do not involve gradation plotting, it also allows the user to adjust the minimum and maximum values displayed on the X- and Y-axes. The tick marks can also be adjusted for scaling the axes. The "Lines/Legends and Scale" dialog box is shown in Figure 10.

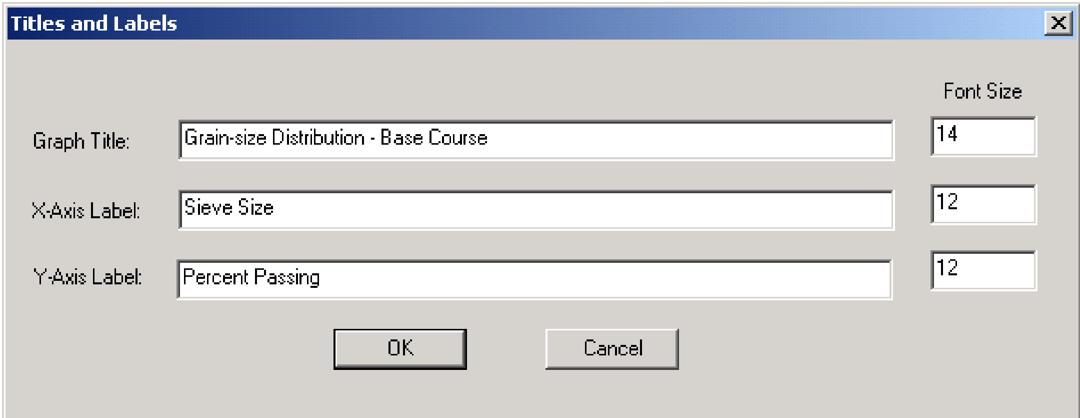


Figure 9. Title and Labels dialog box.

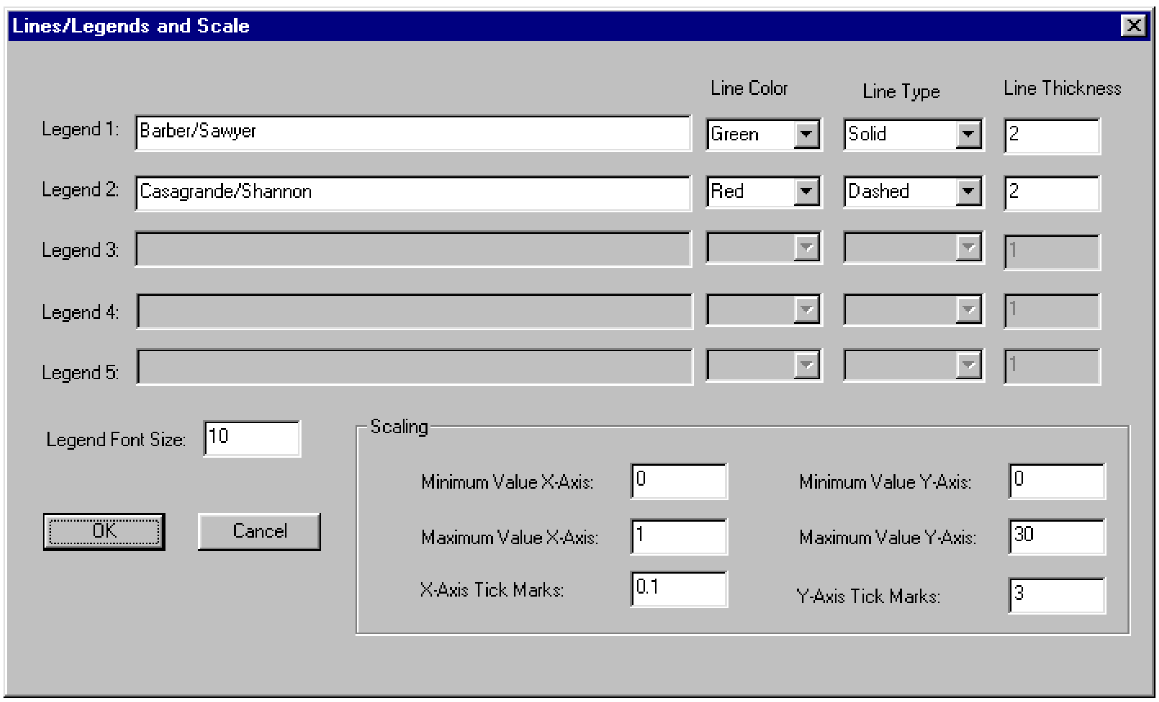


Figure 10. Lines/Legends and Scale dialog box.

When using the above-referenced dialog box, keep in mind:

- Five separate legend entries appear in the box, which is the maximum number of individual series that can appear on a single DRIP plot. For plots with fewer than five series, the additional edit boxes are disabled.
- The Line Color edit boxes control the color of the plots generated by DRIP. The standard line thickness used by a plot generated by DRIP is 2. However, different line thicknesses (from 0 to 10), types (solid, dotted, dashed, and dashed-dot), and colors can be used to identify different series.

- For the sensitivity plots, although the program allows the maximum value for the X-axis to be changed to any number, the plotted data might not be extend over the entire range. This is because the data plotted in the sensitivity charts is precomputed for realistic ranges of the independent value. These ranges are hardcoded into the program and cannot be changed. However, the minimum X-value can be changed to any level to increase the resolution of the plotted graphs.

DRIP Property Pages

DRIP has been arranged to flow smoothly from beginning to end of the design process. This has been accomplished by breaking the entire drainage design process into six sub-processes and developing a tabbed property page for each: ***Roadway Geometry***, ***Sieve Analysis***, ***Inflow*** (with the ***Meltwater*** sub-screen), ***Permeable Base*** design, ***Separator*** layer design, and ***Edgedrain*** design. The user can access any of these property pages by selecting the appropriate tab along the top of the DRIP client window. The layout of the property pages on the DRIP client window (see Figure 1) suggests a logical left-to-right flow of drainage design, which is recommended. However, the program has the flexibility to allow the user to start at any point within the program and to use only a few of the program components including the use of only a single property page. While the property pages can be utilized in a stand-alone manner, they are somewhat interdependent in that the inputs on one page can be taken from the calculations on another. The interdependencies of the DRIP property pages are shown in Figure 11.

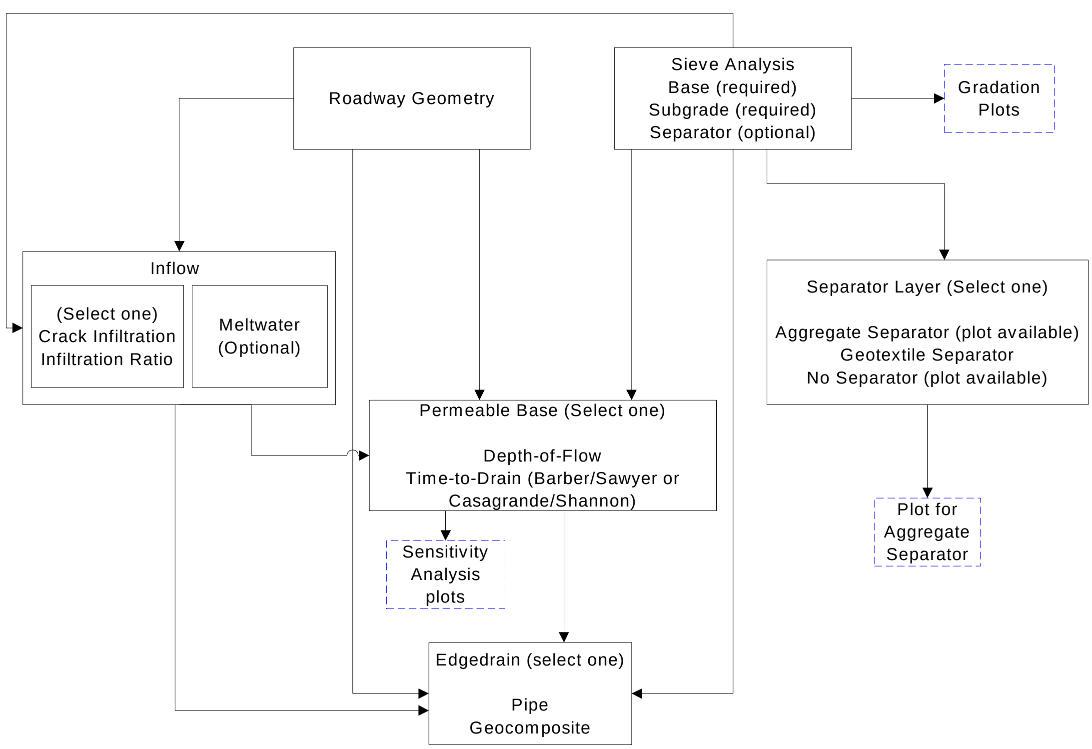


Figure 11. Interdependencies of DRIP property pages.

The ***Sieve Analysis***, ***Inflow***, ***Permeable Base***, ***Separator***, and ***Edgedrain*** screens are actually multiple property pages in one. By selecting a specific analysis type using the radio buttons located in the upper left-hand corner of the property page, the analysis performed by that page can be changed. For example, on the ***Inflow*** property page the user can choose either the *Crack Infiltration* method or the *Infiltration Ratio* method by selecting the appropriate radio button. On the ***Permeable Base*** property page, the analysis can be set either to the *Depth-of-Flow* or the *Time-to-Drain* method, the ***Separator*** property page can design either pavements without or with a separator layer (aggregate or geotextile), and the ***Edgedrain*** property page can be used to design either pipe or geocomposite pavement edgedrains. In addition, a number of other dialog boxes are accessible from within certain property pages. For example, a dialog box for the estimation of the quantity of meltwater using Moulton's chart is available from the ***Meltwater*** property page.

A number of plots are available from the DRIP property pages including 1) depth-of-flow and time-to-drain sensitivity plotting, accessible from the ***Permeable Base*** property page; 2) meltwater inflow plotting, accessible from the ***Inflow*** property page; and 3) aggregate gradation plotting, accessible from the ***Separator*** layer property page or the ***Sieve Analysis*** property page.

<u>Input and Output</u>

DRIP uses standard Windows edit boxes within each property page to display input and output values, which allows the user to input a value for any parameter after positioning the screen cursor over the appropriate edit box and clicking the left mouse button. The user can then type the input value from the keyboard. In many cases, however, it is desirable to let DRIP calculate the parameter value based on user-provided input values for other parameters.

Calculator icons beside the parameter labels identify cases where the variable should be calculated by the program. Calculator icons often are accompanied by an equation that indicates which parameter values must be input. When the required input values have been provided, the calculator icon will become enabled, or "activated"; an active calculator icon is blue in color. By positioning the screen cursor over an active calculator icon and clicking the left mouse button, the value is calculated and displayed in the edit box. Thus, edit boxes are used as the primary means of both input and output.

An alternative method for navigating to the calculator icon is to press the Tab key until the desired button has the focus (i.e., until a faint dotted line appears around the button text). Once the button has the focus, hitting the space bar selects the button.

Even when it is desirable to let the system calculate a value for a specific parameter, the user always has the option to type a value into the edit box. To permit this feature, the program diligently checks for data conflicts to maintain consistency within a design and integrity of the program. Thus, typing a value for a parameter that should be calculated may cause conflicting values for other parameters to be erased.

A list of parameters used in this program is included at the end of this appendix as Appendix UU.1, "Standardized Nomenclature."

Roadway Geometry

Although DRIP operates in a modular manner and the design process can be performed in any order, it is suggested that the user access the ***Roadway Geometry*** property page first. The ***Roadway Geometry*** property page screen is shown in Figure 12. On the upper right side of the screen are two graphics representing the available options—a roadway with crown in the centerline and a roadway that slopes in the same direction on both sides of the centerline. Indicate which geometry best fits the design situation by clicking the appropriate radio button. The equation for width of drainage path W reflects the geometry selection, as will the profile graphic in the middle right side of the screen.

To calculate W, the user must first provide values for the parameters b, the width of pavement surface, and c, the distance from the pavement shoulder to the edge of the permeable base, by entering this data in the appropriate edit box. When values have been supplied for both parameters, the calculator icon beside the parameter W will become activated. Clicking on this icon will cause the value for W to be calculated using the equation shown. In the same manner, when values are provided for longitudinal slope S and cross slope S_X, the calculator icons for resultant slope S_R and resultant length of drainage path L_R are activated.

The calculator icons become activated whenever all data values that are required to evaluate the respective equations are available. The user always has the option to type in a value for the parameter rather than use the equation to calculate it. However, doing so may cause the program to erase values of other parameters (to avoid inconsistencies).

For example, assume that the user has provided values of 9.3 m and 1.2 m for parameters b and c, respectively. Selecting the calculator icon yields a W value of 5.85 m. Now proceed to provide values of 0.05 and 0.03 for S and S_X, respectively, and calculate values of 0.0583 for S_R and 11.37 m for L_R. Now manually edit the value of W, rounding it up to 6 m. Doing so erases the value of c, because the combination of b and c that are provided cannot result in a W value of 6 m. The program also erases the value of L_R, because the value of 11.37 m does not reflect the new design parameter that was provided. This process of erasing data requires the user to recalculate values that reflect new inputs, thereby adding to the integrity of the final design. It also prevents the user from mistakenly assuming that values of dependent parameters are still valid.

A flowchart showing the data flow in the ***Roadway Geometry*** property page is presented in Figure 13.

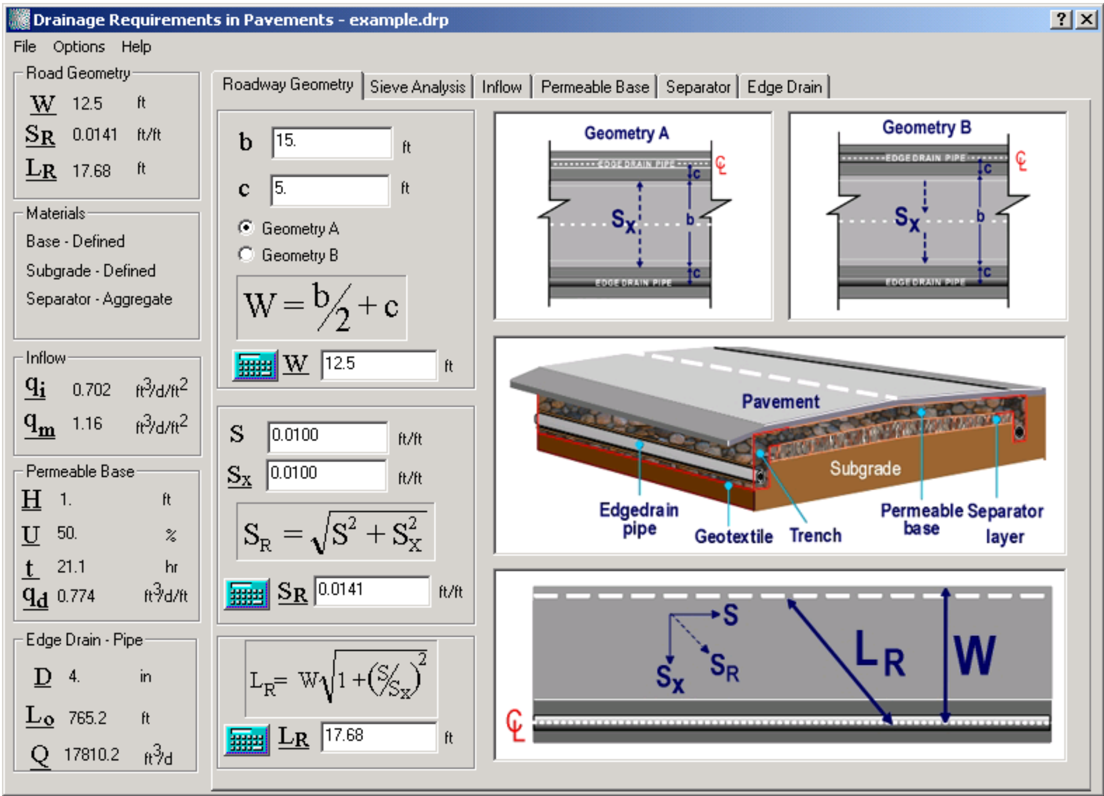


Figure 12. Roadway Geometry property page.

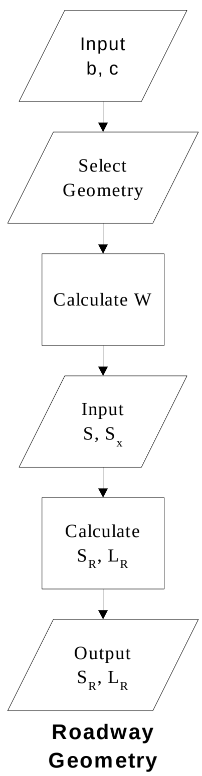


Figure 13. Flowchart for the Roadway Geometry property page.

Sieve Analysis

The ***Sieve Analysis*** property page, shown in Figure 14, is used for gradation analysis and to input other material properties for the base course, separator, and subgrade layers. The spreadsheet-style grid on the left side of the property page is used for entering and editing sieve analysis data. Sieve data may be entered in this grid in any order, and cells may be left blank if data is not available for a particular sieve size. Two types of sieve analysis data entry forms, *Range* and *Value*, are available to the user. The *Range* analysis, selected by the corresponding radio button near the top left side of the property page, allows the user to input a range of sieve data that a particular material is bracketed by. The *Value* analysis requires the user to input a single value at sieve sizes for which data is available. The numbers entered are the percent passing a particular sieve, by weight, and therefore should range from 0 to 100. For example, 100% passing should be input as 100 and 55.3% passing should be input as 55.3.

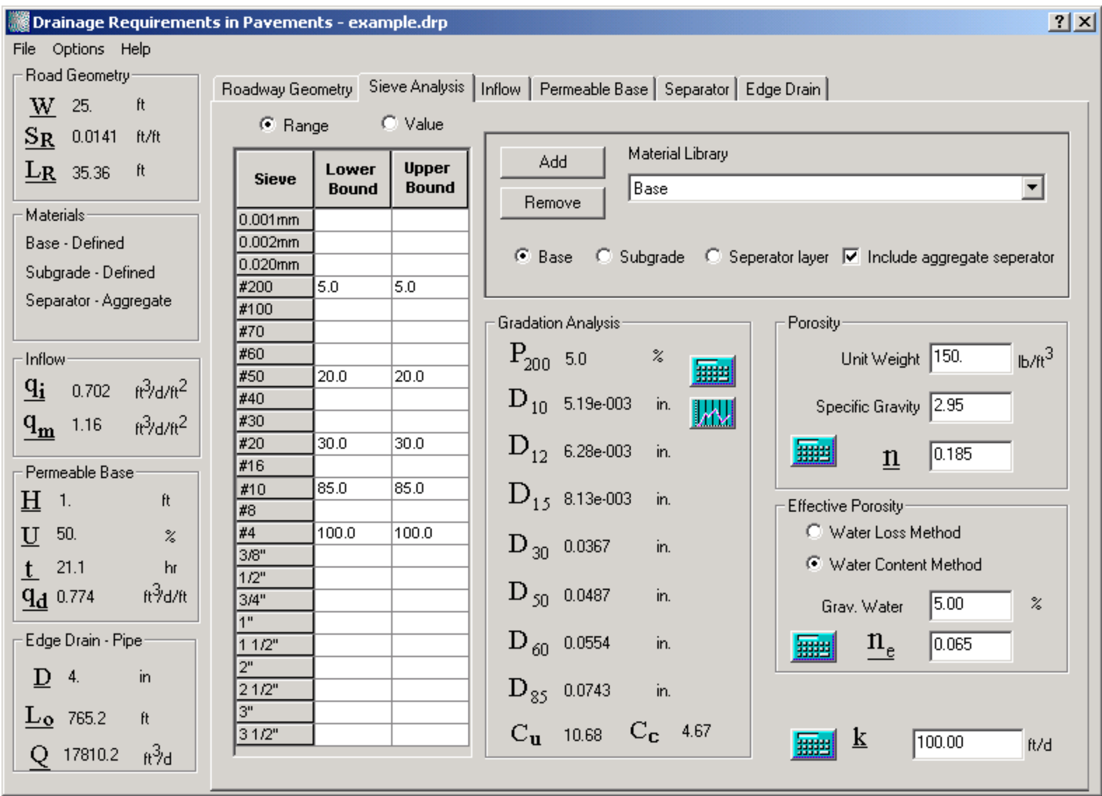


Figure 14. Sieve Analysis property page.

When all of the sieve data has been entered, the user can select the calculator button located in the Gradation Analysis box to perform a grain size distribution analysis. If the entered gradation data is not consistent, DRIP warns the user by changing the font color of the value in question to red. For example if the user entered 50% passing the #4 Sieve, and 100% passing the #8, the number 50.0 would be highlighted in red since it is physically impossible to have such a gradation.

DRIP allows the user to enter both the sieve and hydrometer analysis data when determining grain size distribution. It is important to include the sieve size where less than 10% passes so that the program can properly determine D_{10}. It is also important to include the sieve where at least 85% of the material is passing so D_{85} can be properly determined. When the user selects the calculator button in the Gradation Analysis box, a grain size distribution analysis is performed to calculate effective sizes at different percentages (D_{10}, D_{12}, D_{15}, D_{30}, D_{50}, D_{60}, D_{85}), percent passing the #200 sieve, C_U (coefficient off uniformity), and C_c (coefficient of curvature or gradation).

After the calculator button is selected in the Gradation Analysis category box, the Gradation plot button becomes active. Selecting this button calls DripPlot and displays a grain size distribution plot. The program defaults to a Power 0.45 horizontal scale, but the user may change this to a semi-log scale using the *Options | Plot Scale* menu command. On the main DRIP window, the gradation of the AASHTO #57 material is plotted in Figure 15 on a Power 0.45 chart as an example.

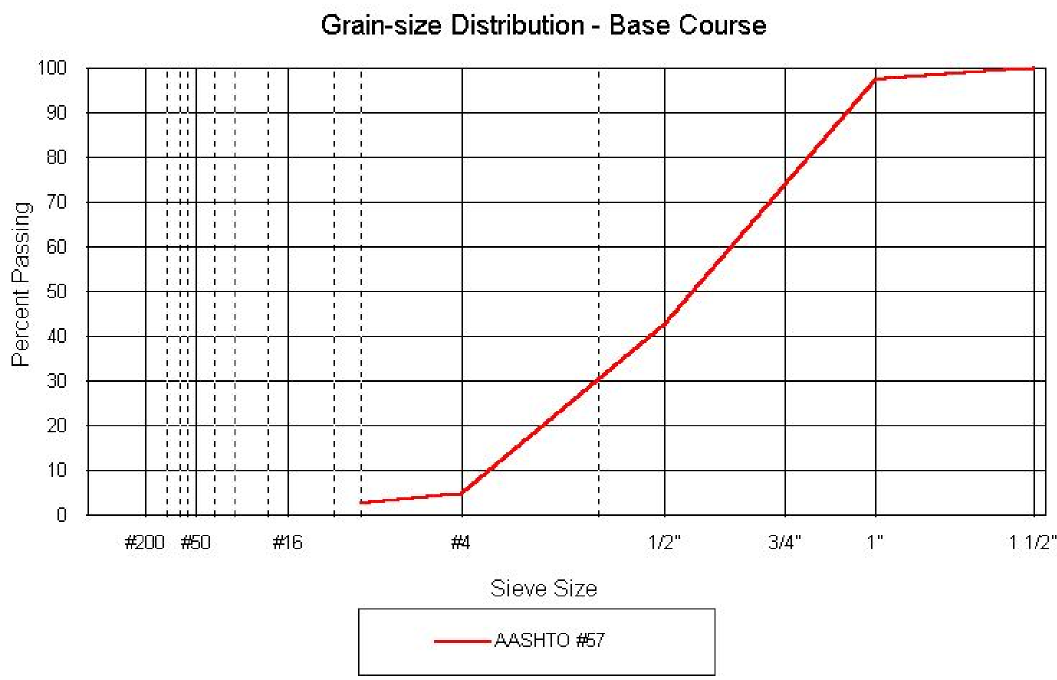


Figure 15. Example output of a value input sieve analysis.

In addition to entering sieve data, DRIP allows the user to select materials from the resident *Material Library*. When a material is selected from the *Material Library*, all of the sieve and property data saved for that material will be entered in the appropriate edit boxes, overwriting the data already present.

The user can also save custom gradation data to the *Material Library* along with other material property information such as unit weight, porosity, and effective porosity by following these simple steps:

1. Select the type of layer—base, subgrade, or separator—for which data will be entered. This can be done by selecting the appropriate radio button on the ***Sieve Analysis*** property page.
2. Select either the *Range* or *Value* data entry form and enter the desired gradation data.
3. Click on the Add button in the Material Library box. Assuming that the input data does not contain inconsistencies, an "Add Gradation to Library" dialog box appears (see Figure 16). If there is an error in gradation data entry, the inconsistent data appears in red colored font and will need to be corrected.
4. Enter a text-based file descriptor that will be also used as a file name. This file name will have the extension .sgd attached to it and will be saved in the GradFiles folder in the DRIP directory. Avoid using any DOS file control characters (*,/,\,:,?) when describing the material.

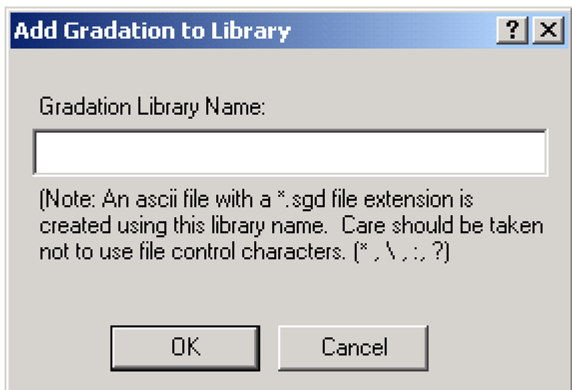


Figure 16. Add gradation to Material Library.

After the material is saved to the *Material Library*, that description will appear in the library pull down list box. If the user edits this file by entering new numbers in the *Sieve Analysis* spreadsheet, the material type will return to <*user defined*>. The <*user defined*> material type is a temporary name and will not be saved if a specific material is selected from the *Material Library*.

Materials that are added to the *Material Library* remain in the library until the file is removed using the Remove button or deleting the appropriate *.sgd file from the GradFiles subdirectory. When a user starts entering data in the sieve analysis spreadsheet, the name of the material changes to <*user defined*>. It is possible to have separate <*user defined*> entries for the base, subgrade, and separator layers.

Besides gradation analysis, the ***Sieve Analysis*** property page requests several other user inputs. These values can be entered directly or calculated using empirical formulae. Permeability, k, of a layer can be calculated using Moulton's empirical formulation, which requires particle size and porosity information. DRIP allows the user to compute porosity after the unit weight and the specific gravity of the material is entered. A more accurate estimation of porosity can be gained through laboratory testing. If such data are available, they should be used in place of the empirical formulae.

Two analysis methods are supplied for computation of the effective porosity, n_e—the water loss method and the water content method. As the user clicks the appropriate radio button for each method, the equation changes accordingly. For fine materials such as subgrades, the water content method is recommended. In order to use this method to estimate n_e, the approximate value of the water content should be entered.

For coarse materials such as permeable bases, the water loss method is recommended. To use this method, the user should first select the *Water Loss Method* radio button. The "Water Loss" dialog box similar to the one shown in Figure 17 opens automatically. This dialog box contains a table that shows values for water loss for P_{200} of 0%, 2.5%, 5%, and 10%, for either gravel or sand materials. The user should indicate the type of fines (filler, sand, or clay) contained in the material by clicking the appropriate radio button. If the user has already calculated P_{200} for the given material, that value will appear as a column in the grid shown in Figure 17. Two water loss values, one for sand and other for gravel, are automatically computed and displayed in the dialog box in the P_{200} column. The user should then select one of the water loss values corresponding to the material being analyzed with the screen cursor. Once the selection is made and the "Water Loss" dialog box is closed by pressing the "OK" button, the selected value appears in the Water Loss edit box on the ***Sieve Analysis*** property page.

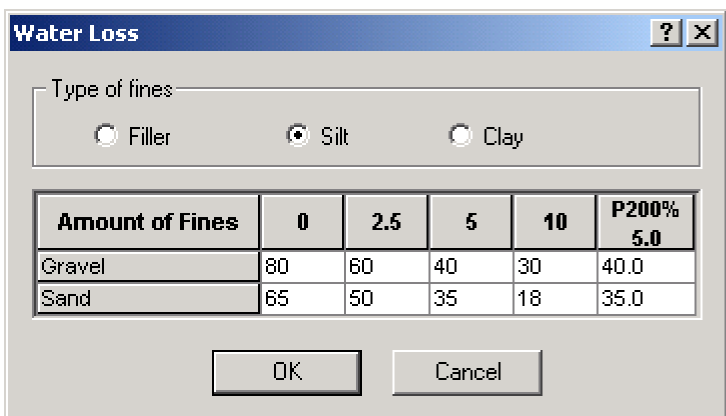


Figure 17. Water Loss dialog box.

Inflow

The next recommended step in a drainage analysis is to calculate the pavement infiltration due to rainfall and meltwater (where applicable). This calculation is handled in the ***Inflow*** property page. The user can perform this calculation using the Infiltration Ratio method or the Crack Infiltration method by selecting the appropriate radio buttons. By default the program uses the latter method. Adding meltwater to the inflow calculation can be enabled or disabled by means of the *Include Meltwater* check box.

The ***Inflow*** property page configured for the Infiltration Ratio method is shown in Figure 18. In the Infiltration Method category box, the user can indicate whether the surface is

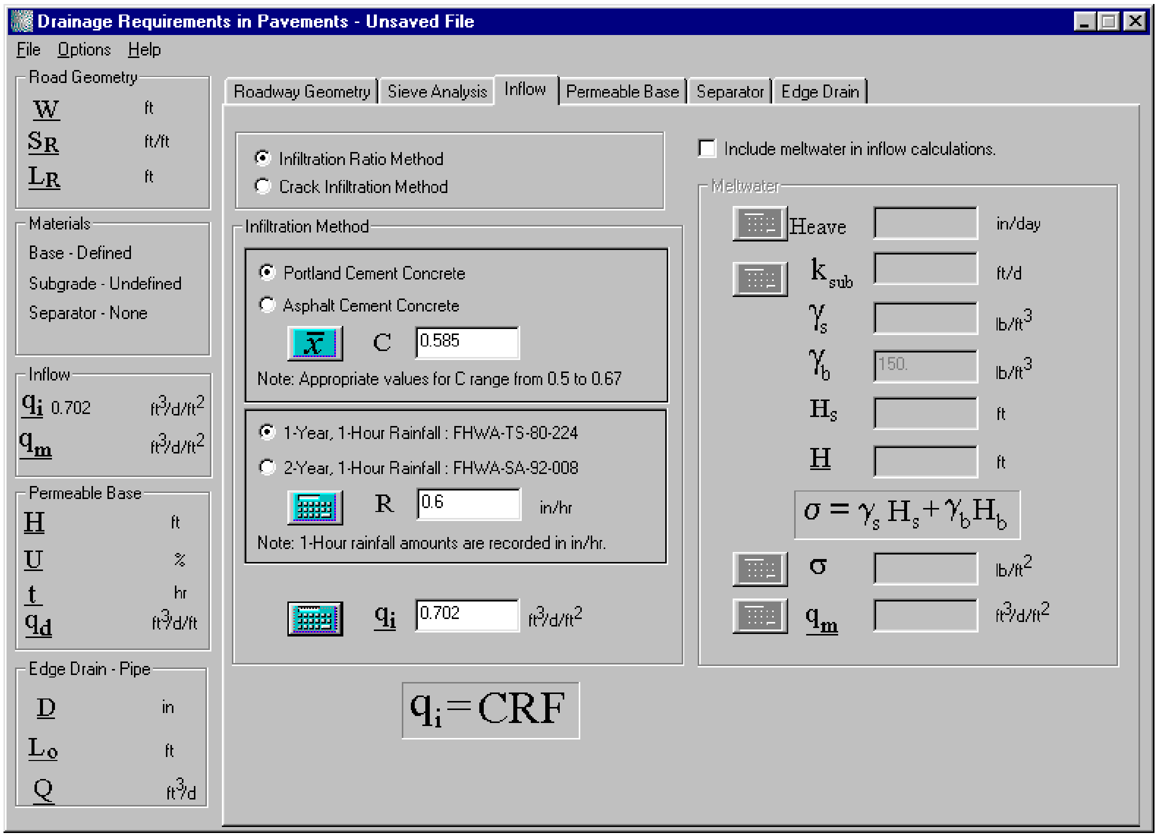


Figure 18. Inflow (Infiltration Ratio) property page.

asphalt or concrete by clicking the appropriate radio button. The range of acceptable values for infiltration coefficient *C* is noted below the edit box. The user may type an estimate of the value in the edit box or click the $\bar{x}$ icon to automatically fill the edit box with the midpoint value. Changing the surface type will erase any displayed value of *C* and will require the user to provide a new value.

The lower portion of the screen allows the user to type in a value for the rainfall rate *R*, which can be approximated from the rainfall map displayed in online help when the calculator icon is pressed. By default, the program displays the map for a 2-year, 1-hour storm, which is recommended in FHWA report number FHWA-SA-92-008. The user can opt to display instead the map for a 1-year, 1-hour storm, which is recommended in FHWA-TS-80-224. Both maps show *R* values in units of in/hr, so if the analysis is employing metric units, the user needs to manually convert these values to their metric equivalent.

When values have been provided for both *R* and *C*, the calculator icon for inflow, q_i, is activated. Clicking the icon will calculate q_i using the equation shown.

The ***Inflow*** screen for the Crack Infiltration method is shown in Figure 19. When the program begins, the crack infiltration rate I_C has a default value of 2.4 ft^3/day/ft (0.22

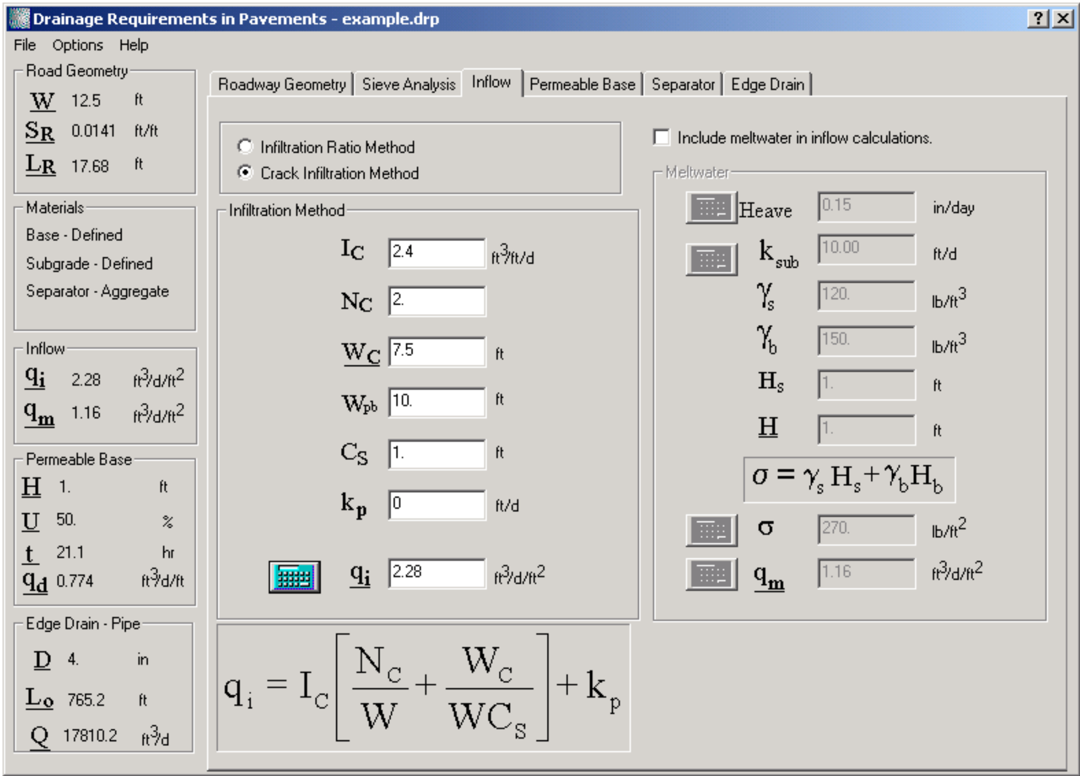


Figure 19. Inflow (Crack Infiltration) property page.

m^3/day/m). Some other input parameter values may already be filled in when the property page is first selected if they have been generated by previous inputs and calculations. For example, if the user calculated W = 5.85 m on the ***Roadway Geometry*** screen using Geometry A and values of 9.3 m and 1.2 m for b and c, respectively, then the W edit box will contain the number 5.85 and the edit box for width of pavement W_C will contain the number 4.65 (or $b/2$). Other parameters to be supplied are permeability k_p of the pavement surface, transverse crack spacing C_S, and number of contributing longitudinal cracks N_C. N_C is generally equal to one plus the number of contributing traffic lanes. When values are provided for all these parameters, the calculator icon for q_i will be activated, allowing the calculation to be performed. The user should compare the value calculated here to the value calculated using the Infiltration Ratio method, and choose the larger number for the sake of conservatism.

Along the same conservative vein, the user may wish to include meltwater in the total inflow calculation. The ***Inflow*** property page with the *Include Meltwater* box checked is shown in Figure 20. The heave rates for different types of subgrade soils can be determined by selecting the calculator icon to the left of the *Heave* edit box label. A "Heave Determination" dialog box such as the one shown in Figure 21 will open. This dialog box presents minimum and maximum heave rates for a variety of soil types with different ranges of minus 200 material. In some cases, the lower bound heave rates are the same as upper bound heave rates, indicating that there is very little variability in the data. The user may use this table to estimate a heave rate for a given soil type and manually enter it into the *Heave* edit box, or alternatively obtain the value by clicking on the desired row in the table. If the latter method is used, the midpoint of the selected

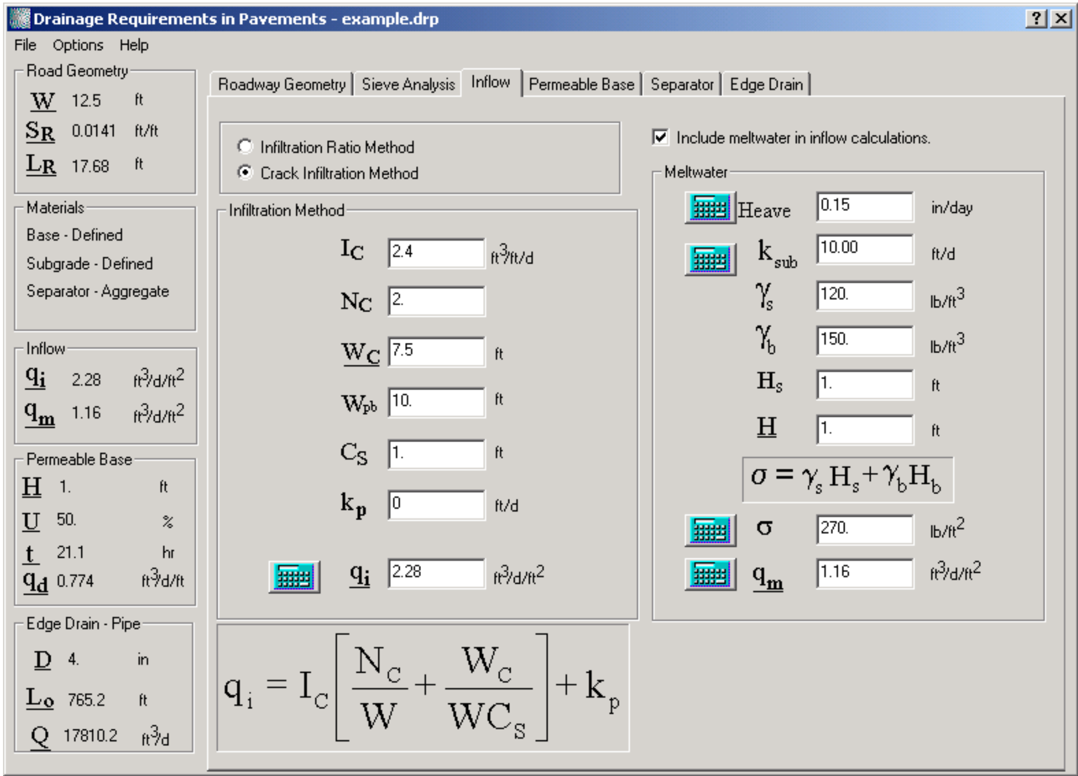
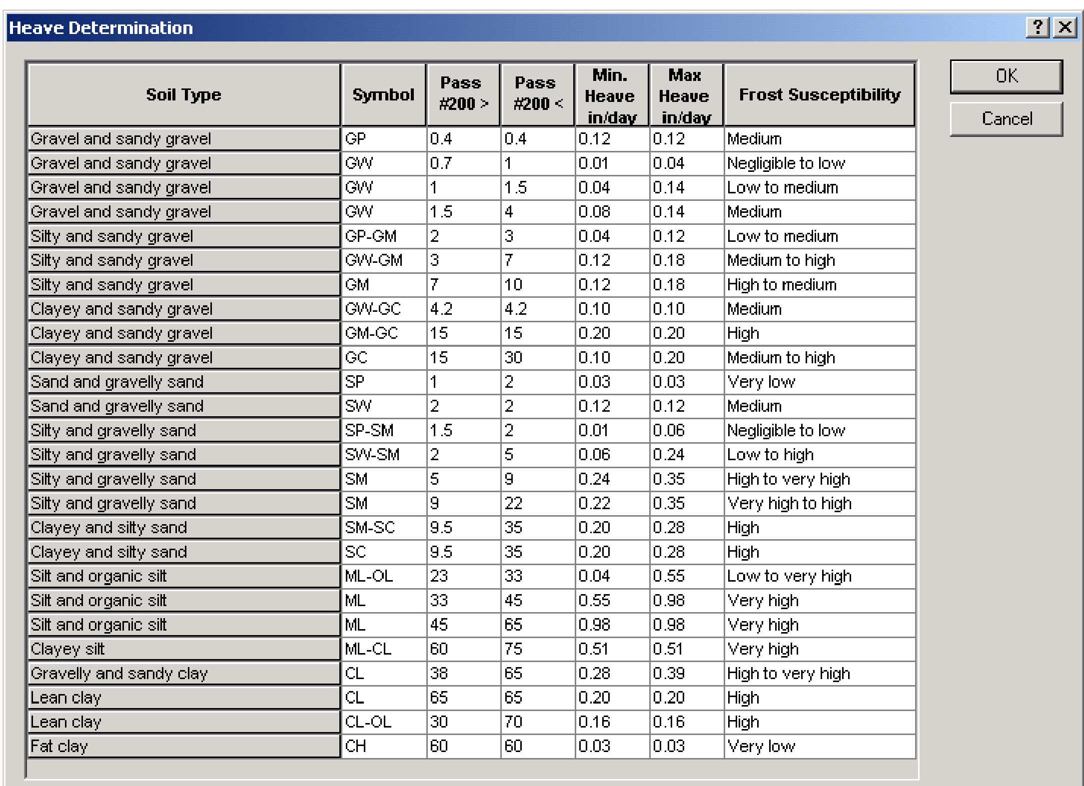


Figure 20. Inflow calculation with Meltwater included.



Soil Type	Symbol	Pass #200 >	Pass #200 <	Min. Heave in/day	Max Heave in/day	Frost Susceptibility
Gravel and sandy gravel	GP	0.4	0.4	0.12	0.12	Medium
Gravel and sandy gravel	GW	0.7	1	0.01	0.04	Negligible to low
Gravel and sandy gravel	GW	1	1.5	0.04	0.14	Low to medium
Gravel and sandy gravel	GW	1.5	4	0.08	0.14	Medium
Silty and sandy gravel	GP-GM	2	3	0.04	0.12	Low to medium
Silty and sandy gravel	GW-GM	3	7	0.12	0.18	Medium to high
Silty and sandy gravel	GM	7	10	0.12	0.18	High to medium
Clayey and sandy gravel	GW-GC	4.2	4.2	0.10	0.10	Medium
Clayey and sandy gravel	GM-GC	15	15	0.20	0.20	High
Clayey and sandy gravel	GC	15	30	0.10	0.20	Medium to high
Sand and gravelly sand	SP	1	2	0.03	0.03	Very low
Sand and gravelly sand	SW	2	2	0.12	0.12	Medium
Silty and gravelly sand	SP-SM	1.5	2	0.01	0.06	Negligible to low
Silty and gravelly sand	SW-SM	2	5	0.06	0.24	Low to high
Silty and gravelly sand	SM	5	9	0.24	0.35	High to very high
Silty and gravelly sand	SM	9	22	0.22	0.35	Very high to high
Clayey and silty sand	SM-SC	9.5	35	0.20	0.28	High
Clayey and silty sand	SC	9.5	35	0.20	0.28	High
Silt and organic silt	ML-OL	23	33	0.04	0.55	Low to very high
Silt and organic silt	ML	33	45	0.55	0.98	Very high
Silt and organic silt	ML	45	65	0.98	0.98	Very high
Clayey silt	ML-CL	60	75	0.51	0.51	Very high
Gravelly and sandy clay	CL	38	65	0.28	0.39	High to very high
Lean clay	CL	65	65	0.20	0.20	High
Lean clay	CL-OL	30	70	0.16	0.16	High
Fat clay	CH	60	60	0.03	0.03	Very low

Figure 21. Heave determination dialog box.

range of heave values will automatically appear in the edit box. In addition to heave rate determination, the user should also provide a value of subgrade permeability k_{sub}. An estimate of the subgrade permeability can be directly entered based on laboratory test data or can be determined based on sieve data. Selecting the calculator icon next to the k_{sub} edit box returns the user to the ***Sieve Analysis*** property page from where this parameter can be estimated. The other parameter required to estimate inflow due to meltwater is load of the pavement structure, σ, which includes loads from both the pavement surface and the base. The user can either directly enter a value for σ, if it is known *a priori*, or can compute it by first entering values for unit weights γ_p and γ_b and the thickness H_S and H of the pavement surface and base, respectively, and then clicking on the calculator icon to the left of the σ label.

When values have been provided for σ, k_{sub}, and the *Heave* rate, the graph icon for meltwater, q_m, is activated. The user can click this icon to display Moulton's chart for estimation of meltwater shown below in Figure 22. The vertical axis represents heave rate, in mm/day, and a red line is drawn to indicate the heave rate value. The user can move the mouse to drag a crosshair along the red line. The horizontal axis represents $q_m/\sqrt{k_{sub}}$. The curves on the graph represent multiple values of σ, in units of lb/ft^2. The values of k_{sub}, σ, and heave rate are displayed at the top of the screen in the required units, as is the current position of the cursor with respect to the horizontal axis. Position the crosshair at a graph location indicative of the value of σ, and click the mouse button. The value of q_m will be calculated and displayed at the top of the screen. When this dialog box is exited, the calculated value will appear in the q_m edit box on the ***Meltwater*** screen.

Example – Meltwater Computation

Assume for this example that the subgrade permeability (k_{sub}) is 100 ft/day, the heave rate (*Heave*) is 0.1 in/day, and the vertical stress on the top of the subgrade (σ) is 200 lb/ft^2. Enter these values in the appropriate edit boxes and click on the graph icon to determine q_m. Moulton's meltwater chart appears on the screen. On this chart a horizontal red line marking the entered heave rate of the subgrade (0.1 in/day) appears. In order to compute the meltwater, the computer mouse can be used to slide the vertical tick line along the horizontal red line to the location where σ is approximately 200 lb/ft^2. When the mouse is at the right position the value for $q_m/\sqrt{k_{sub}}$ should read 0.36. A left click of the mouse button will then produce a value for q_m of 3.61 ft^3/day/ft^2. This value is transported to the q_m edit box on the ***Inflow*** property page when the "Evaluation of the Meltwater Inflow" dialog box is closed.

While including meltwater is a conservative approach, engineering judgment may need to be exercized in adding this value the pavement infiltration from rainfall – q_i. The combined inflow of q_i and q_m could be unreasonably high in some situations.

A flowchart illustrating the data flow on the ***Inflow*** property page is presented in Figure 23.

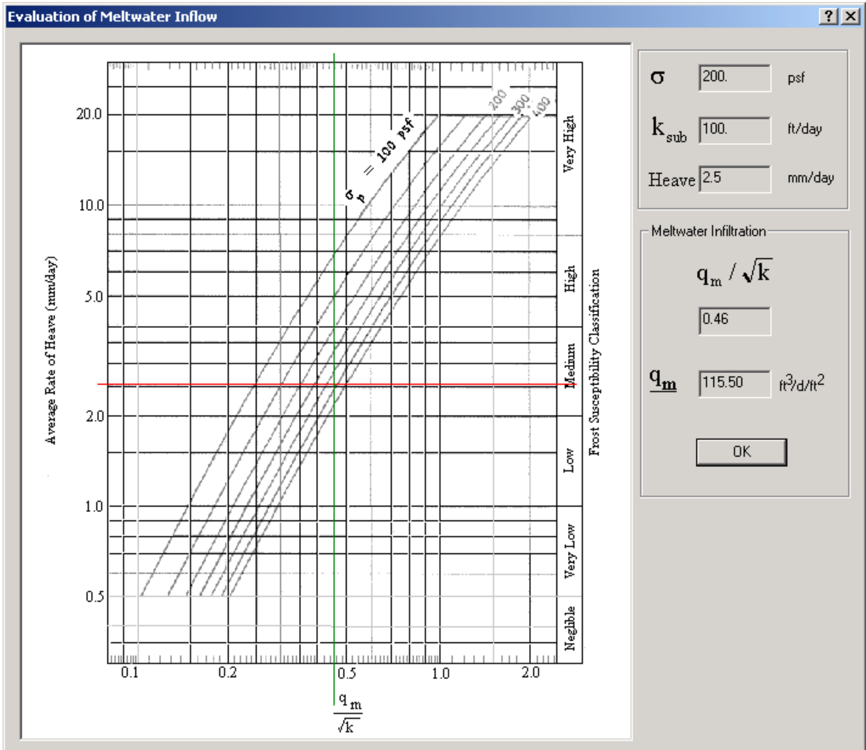


Figure 22. Meltwater inflow computation dialog box.

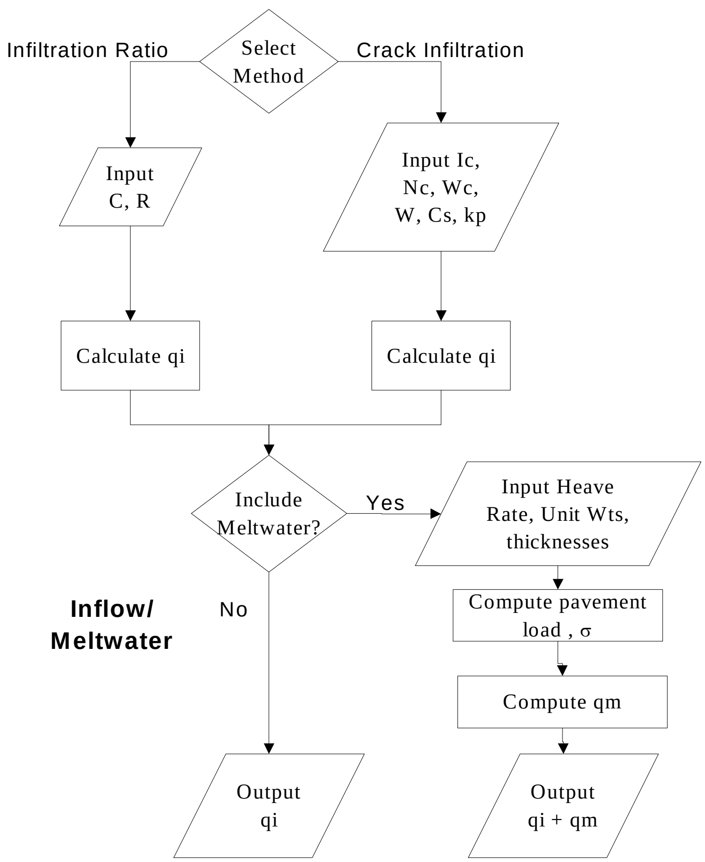


Figure 23. Flowchart for the Inflow property page.

Permeable Base

On the top left corner of the ***Permeable Base*** property page, the user may choose whether to design the permeable base based on depth-of-flow or time-to-drain criteria by clicking the appropriate radio buttons. It is suggested that total inflow be calculated before attempting to perform the base design using the depth-of-flow method. The ***Permeable Base*** property page configured for the depth-of-flow method is shown in Figure 24.

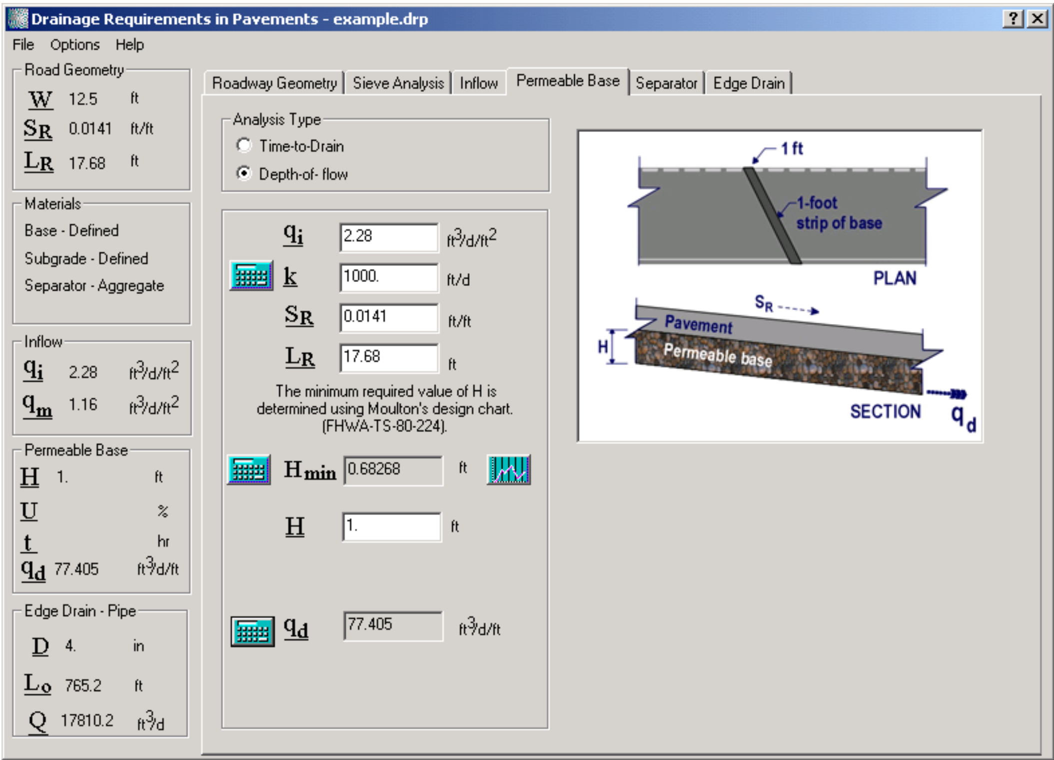


Figure 24. Permeable Base (depth-of-flow) property page.

If the left-to-right hydraulic design flow recommended in this manual is followed, values for several parameters will already be present on this screen. For example, S_R and L_R will have been calculated on the ***Roadway Geometry*** property page, q_i will have been calculated on the ***Inflow*** property page, and a value for *H* may have also been provided on the ***Inflow*** property page. If these values are not present, they may be manually entered in the appropriate edit boxes on this screen. However, for hyperlinked variables (all variables identified with an underline), a more correct procedure would be to first identify the appropriate property pages where these inputs should be logically entered, and then entering them there. In addition to these variables, the user will also need to provide a value for permeability, *k*, of the permeable base. It is recommended in hydraulic design practice that this value be obtained directly from laboratory testing. The laboratory *k* value, if available, can be directly entered on this screen. Alternatively, the user may click the calculator icon located to the left of this parameter to estimate permeability based on the gradation of the permeable base aggregate. This action will take the user to the ***Sieve Analysis*** property page where the computation can be made.

However, it must be noted here that the underlying statistical relationship that estimates permeability from the gradation data was derived for materials with a significant quantity of material passing the #200 sieve. Therefore, it may not be very suitable for estimating the permeability of open-graded materials, which typically have very low percent passing the #200 sieve.

When values have been provided for q_i, k, S_R, and L_R, the calculator and graph icons beside the H_{min} parameter are activated. If the calculator icon is clicked at this point, the program will use the equations underlying Moulton's permeable base design chart to calculate the minimum required thickness H_{min} of the permeable base. The user should check to make sure that the input value of H is greater than the minimum thickness required, H_{min}. Clicking the graph icon to the right of the H_{min} edit box will plot the calculated value of H_{min} over a given range of values for the independent parameters selected in the *Options | Sensitivity* menu command. This allows the user to analyze the sensitivity of the design to variations in inputs. A few typical sensitivity plots for the depth-of-flow method are shown in Figure 25 and Figure 26.

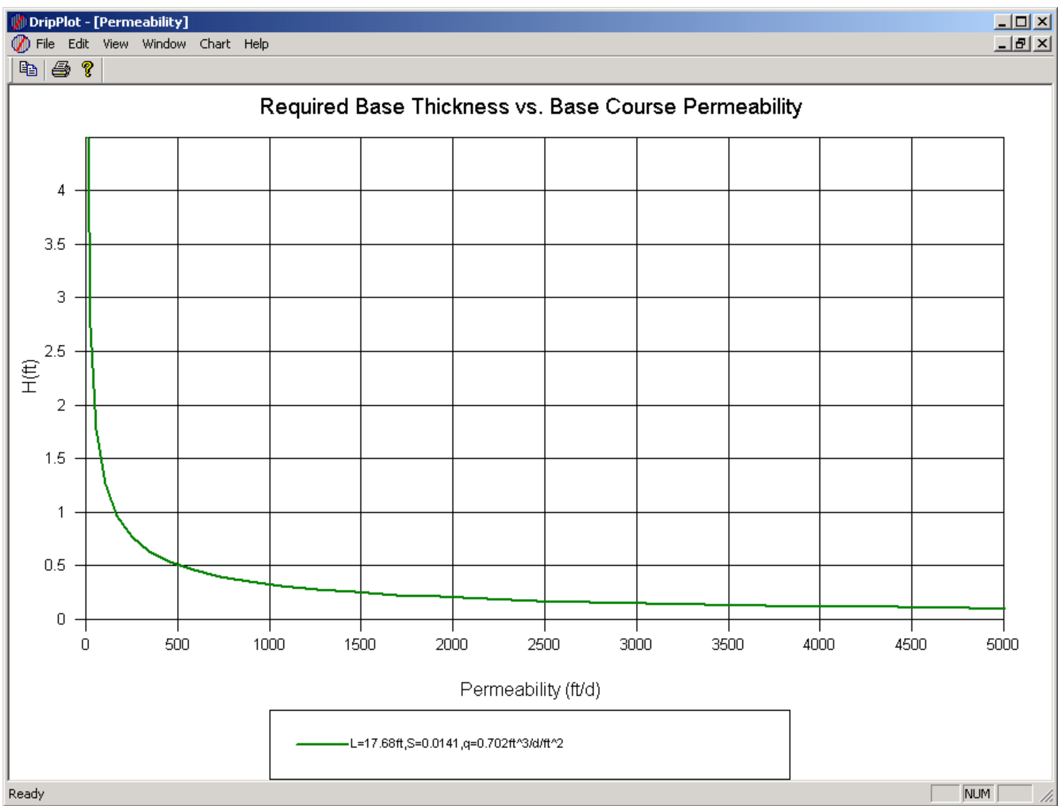


Figure 25. Sensitivity analysis for the depth-of-flow method – base permeability versus base thickness.

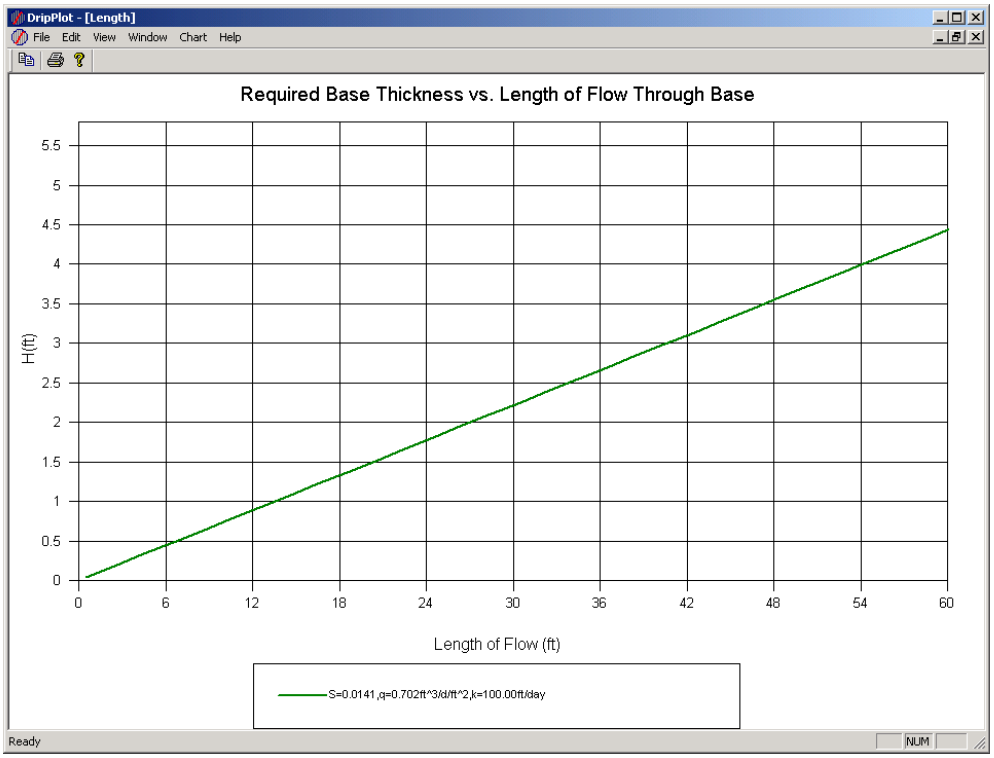


Figure 26. Sensitivity analysis for the depth-of-flow method – length of flow versus base thickness.

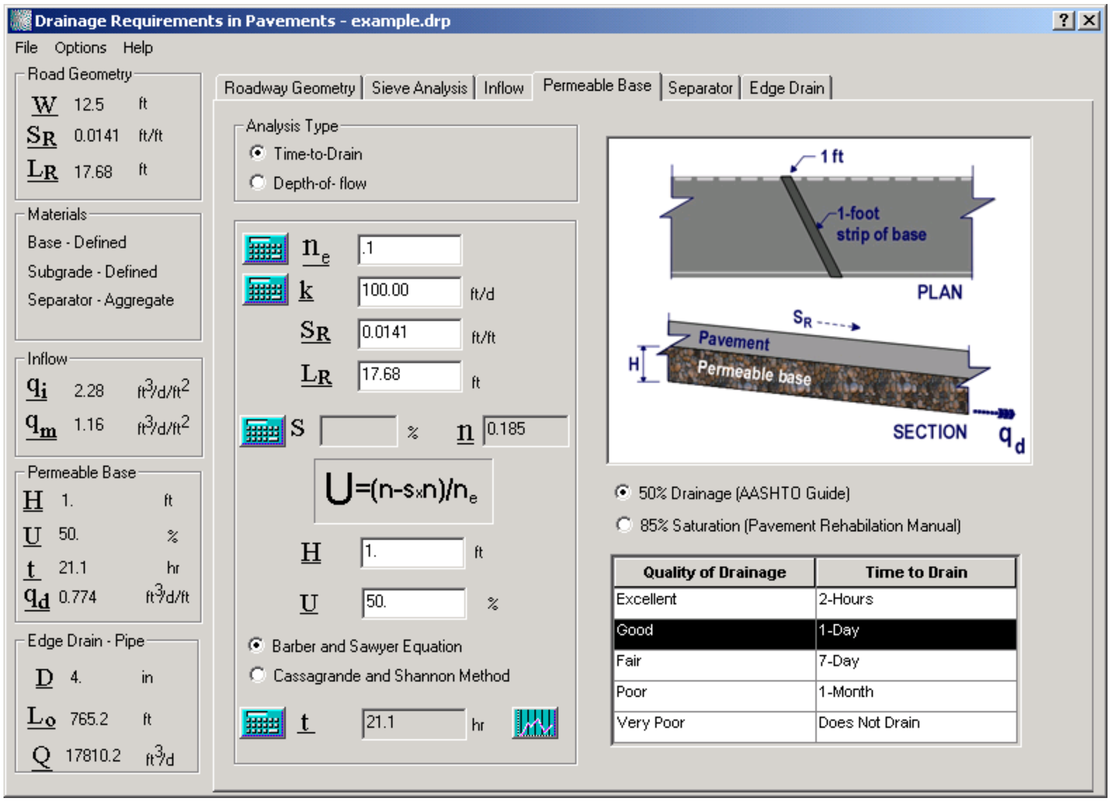


Figure 27. Permeable Base (time-to-drain) property page.

Once the user is satisfied that the value provided for base thickness *H* is sufficient to handle any possible variations in the design parameters, the capacity of the permeable base, q_d, can be computed by clicking the calculator icon located to the left of the corresponding label.

The ***Permeable Base*** property page configured for the time-to-drain method is shown in Figure 27. As with the depth-of-flow method, values would already have been supplied for many of the parameters from previous screens. There are calculator icon buttons beside the labels for permeability *k* and effective porosity n_e that the user can click to call the ***Sieve Analysis*** property page. Estimated values for these parameters can be determined based on aggregate gradation input in that page. However, it is recommended that these values be obtained instead through laboratory testing. Once the values for *k*, n_e, S_R, L_R, *H*, and percent drainage *U*, are supplied, the user can click the calculator icon to determine the time required to drain, *t*. By default, the parameter *t* is estimated using the Barber and Sawyer equation. Alternatively, if the Casagrande and Shannon Method is the preferred method, the corresponding radio button must be first selected and the calculator button next the *t* parameter clicked to compute the appropriate value.

The resulting value for time *t* required for drainage from either methods can be compared to the table on the right-hand side of the screen to estimate the permeable base quality of drainage. By default, the table displays the quality of drainage based on the AASHTO 50 percent drained criteria. Alternatively, the user can choose to display base drainage quality based on the pavement rehabilitation manual 85% saturation criteria by clicking the appropriate radio button. To translate these criteria to the current design parameters, the user should select the given equation to calculate percent saturation from the values of *n*, n_e, and *U*. The user may have to modify the value of *U* until it results in a value of $S \cong$ 85%.

As with the depth-of-flow screen, the time-to-drain screen also provides sensitivity plotting. These plots can be accessed by clicking on the graph icon located to the right of the time-to-drain parameter *t* on the ***Permeable Base*** property page. Prior to clicking this icon, the independent parameters to be plotted on the horizontal axis against the dependent variable *t* need to be selected using the *Options | Sensitivity* menu command. The sensitivity plots always include the results computed using both Barber and Sawyer as well as the Cassagrande and Shannon equations. A typical sensitivity analysis plot from the time-to-drain analysis is presented in Figure 28. In this figure, the time-to- drain parameter *t* is plotted against the degree of drainage, *U*. It can be observed from the figure that as the degree of drainage approaches 100 percent, the time to drain increases exponentially. Note that *U* is expressed as a fraction in the Figure 28.

A flowchart depicting the data flow in the Permeable Base property page is shown in Figure 29.

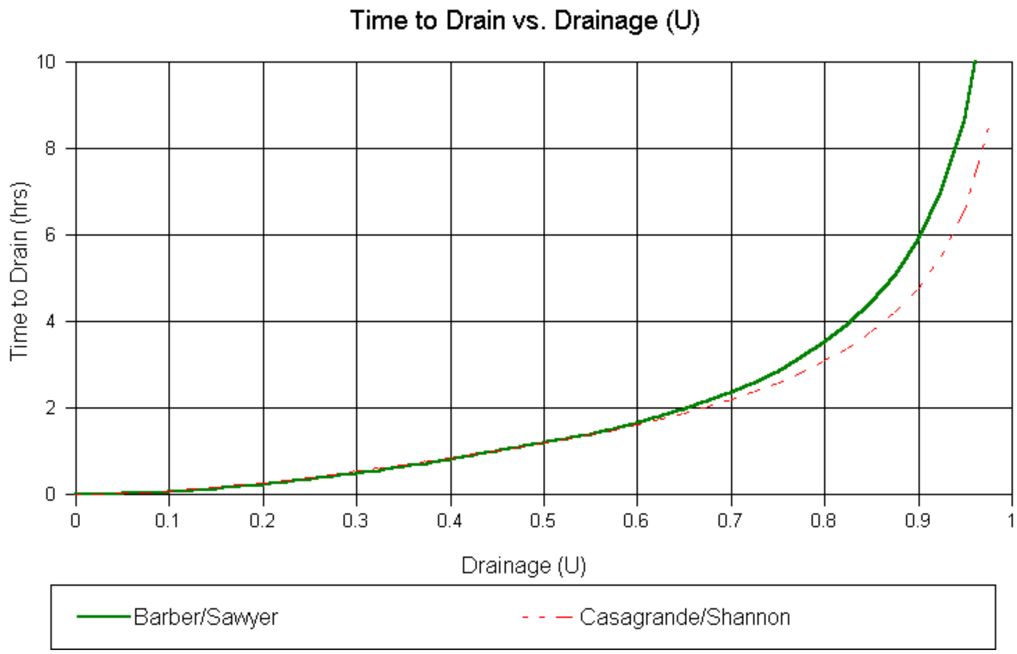


Figure 28. Sensitivity plot for the time-to-drain analysis – time to drain versus degree of drainage.

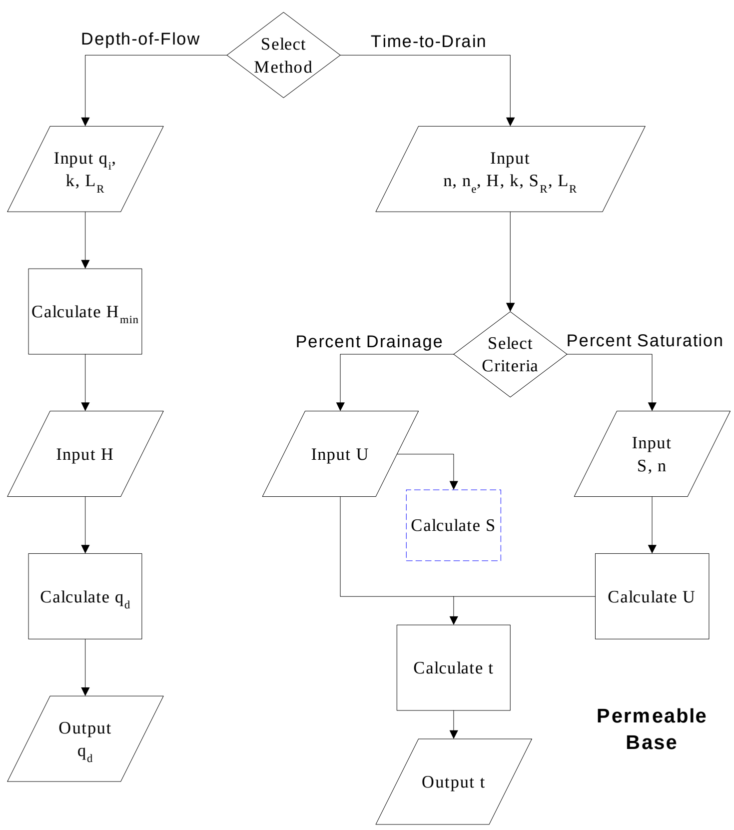


Figure 29. Flowchart for the Permeable Base property page.

Separator Layer

The default screen that appears when the ***Separator*** property page is first selected during a DRIP session is the configured for the *No Separator* option. If a design is performed using this option, DRIP will determine whether a separator layer is required. If instead the user wishes to perform an aggregate separator layer design, the appropriate radio button located on the left top of the property page should be clicked. The design screen configuration after this selection is made is shown in Figure 30. The right side of the design screen displays particle size criteria to prevent intermixing of layers. The left side of the screen allows the user to input particle size values (e.g., D_{10}, D_{15}, D_{50}, and D_{85}) for the permeable base, subgrade, and separator layers. These values should already be present if a complete gradation analysis has been completed for all the materials on the ***Sieve Analysis*** property page. If the particle size values are missing for any given layer, the user should go to the ***Sieve Analysis*** property page to compute these values. This can be done either by clicking the calculator button adjacent to the layer in question or by clicking the Sieve Analysis tab on the DRIP client window. When all the required D_x values are configured, the balance and graph icons on the right side of the screen turn blue in color. By clicking on the balance icon, the aggregate separator layer design criteria can be checked.

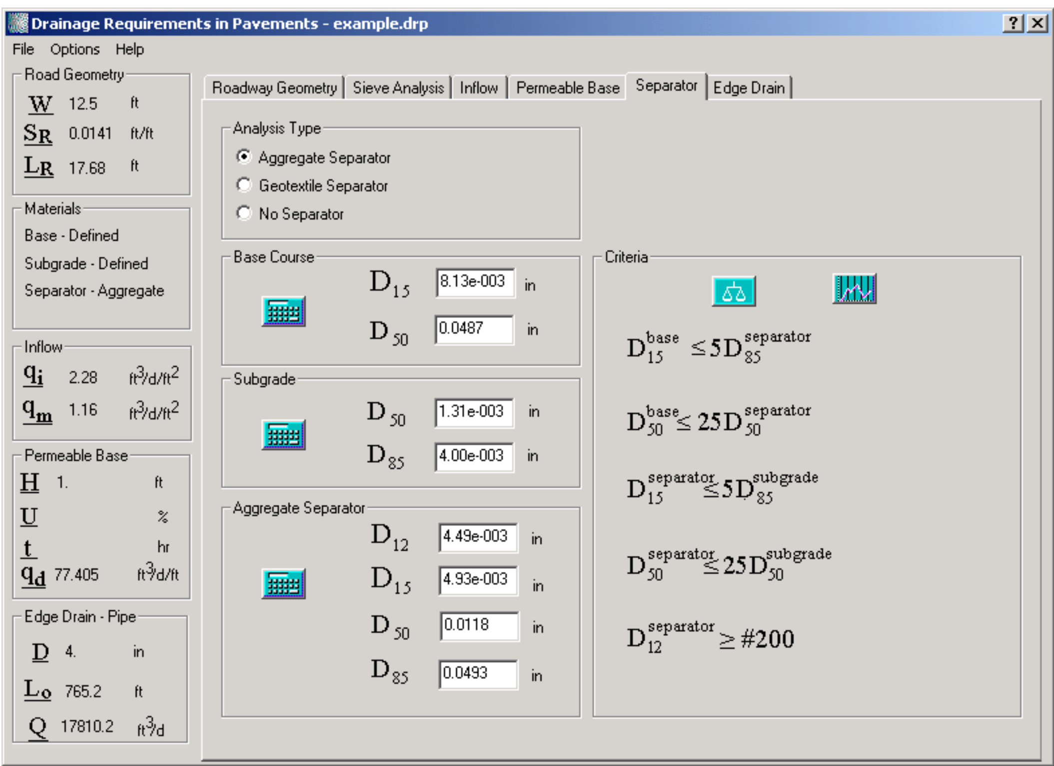


Figure 30. Separator (aggregate separator layer) property page.

After DRIP determines whether the design passes the necessary separator layer criteria, left-clicking the graph icon located in the Criteria category box will generate a plot which graphically summarizes the design performed. For an aggregate separator layer design, this plot contains the gradation plots of the subgrade, the base course, and the separator layer. In addition, the numerical values of the design criteria are also plotted and are represented using red triangles. The right-pointing triangles denote the lower limit, while the left-pointing triangles denote the upper limit of the desired gradation band for the separator layer.

A sample plot generated from the ***Separator*** property page is shown in Figure 31. If a chosen separator layer passes all the required design criteria, its gradation should fall within this desired band as illustrated in Figure 31. As with the plots generated on the ***Sieve Analysis*** property page, either a Power 0.45 or a logarithmic scale can be employed for the horizontal axis for this plot.

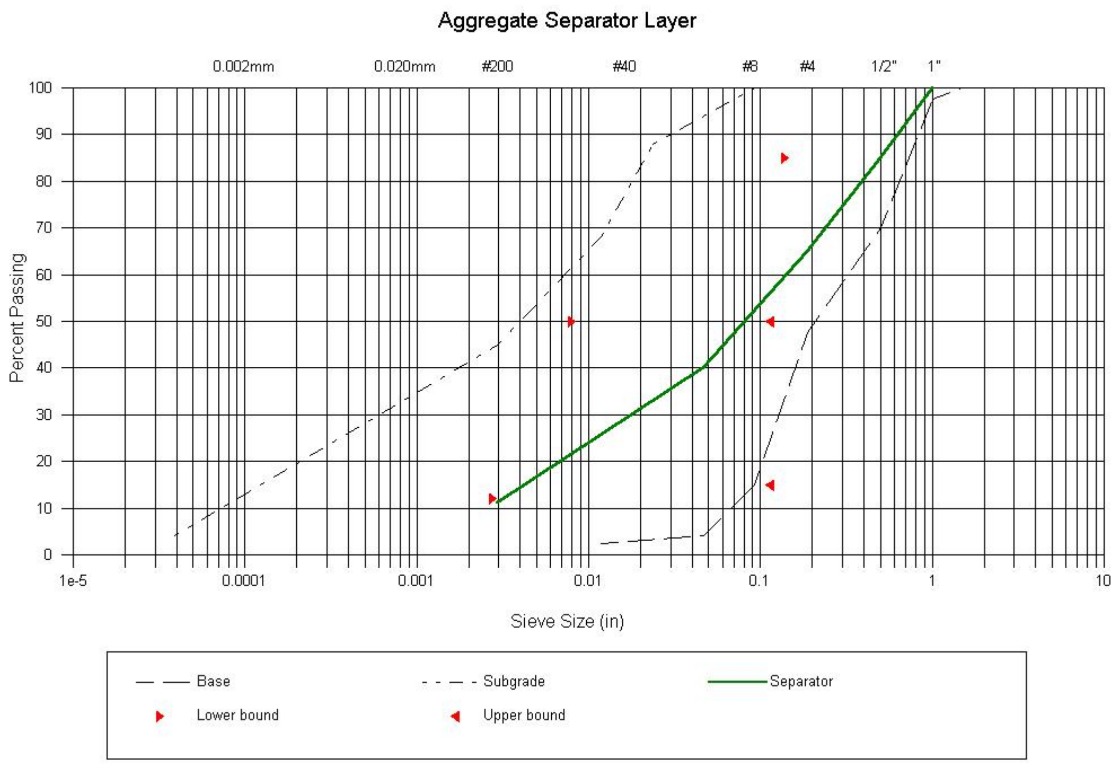


Figure 31. Separator (aggregate separator) Power 45 plot.

Figure 32 presents the ***Separator*** property page configured for performing a geotextile separator layer design. Selecting the *Geotextile Separator* radio button enables this analysis screen. As with the aggregate separator layer analysis, the design criteria for the geotextile separator layer are also displayed on the right-hand side of the screen. The criteria displayed are dependent on the user's selections for soil retention criteria (steady-state or dynamic flow), permeability/permittivity criteria (normal or critical), clogging criteria (normal or critical), and the amount of fines in the subgrade material (P_{200}).

Material properties for the subgrade should already be in the edit boxes, carried over from the ***Sieve Analysis*** property page. After the necessary values have been provided for all the subgrade parameters, the calculator icon in the Separator Layer category box becomes enabled. Clicking this button determines the maximum allowable apparent

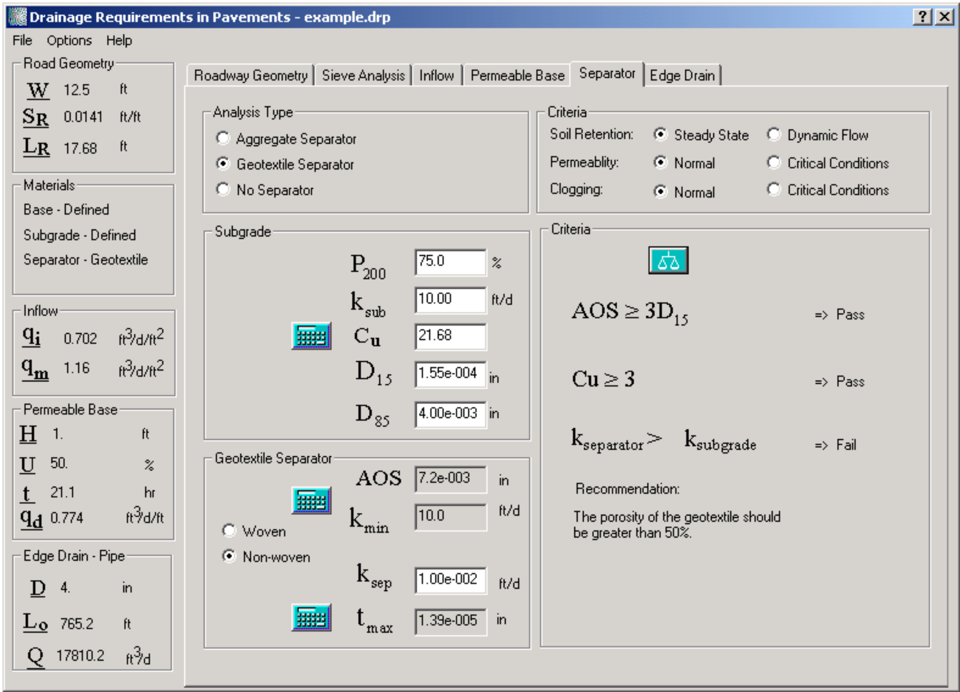


Figure 32. Separator (geotextile separator) property page.

opening size *AOS* of the geotextile and the minimum allowable permeability k_{min} of the geotextile. Typically, at this stage, in design, a geotextile that satisfies the *AOS* and k_{min} requirements is selected and its actual permeability is entered in the k_{sep} edit box. The calculator icon for t_{max} will then become enabled and the maximum allowable thickness of the geotextile for permittivity requirements can be computed. Note that the recommendation at the bottom of the screen changes based on the geotextile type.

A flowchart illustrating the data flow of the ***Separator*** property page is shown in Figure 33.

<u>Edgedrain</u>

In the upper left-hand corner of the ***Edgedrain*** property page select either the *Pipe* or *Geocomposite* radio button to identify the type of edgedrain. The *Pipe Edgedrain* analysis screen is shown in Figure 34. Typical values for Manning's roughness coefficient, $n_{manning}$, for smooth and corrugated pipes are provided on the right-hand side of the screen. If $n_{manning}$ for the pipe being analyzed is unknown, one of these typical values can be adopted by selecting the appropriate check box. Once the user has supplied values for $n_{manning}$, slope *S* of the edgedrain (by default the longitudinal slope), and pipe diameter *D*, the calculator icon for pipe capacity *Q* becomes activated and can be clicked to calculate the quantity.

After calculating *Q*, there are three options for determining the required outlet spacing. The *Pavement Infiltration* approach is based on the estimated inflow into the permeable base; this is the default selection in DRIP. The *Permeable Base* approach is based on the

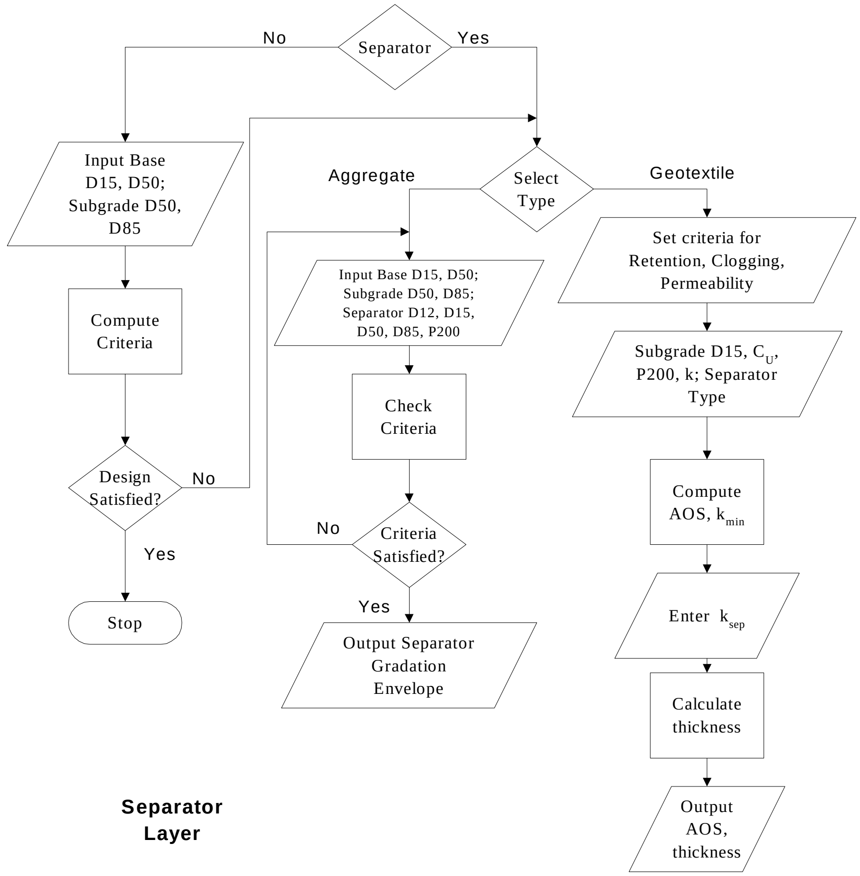


Figure 33. Flowchart for the Separator property page.

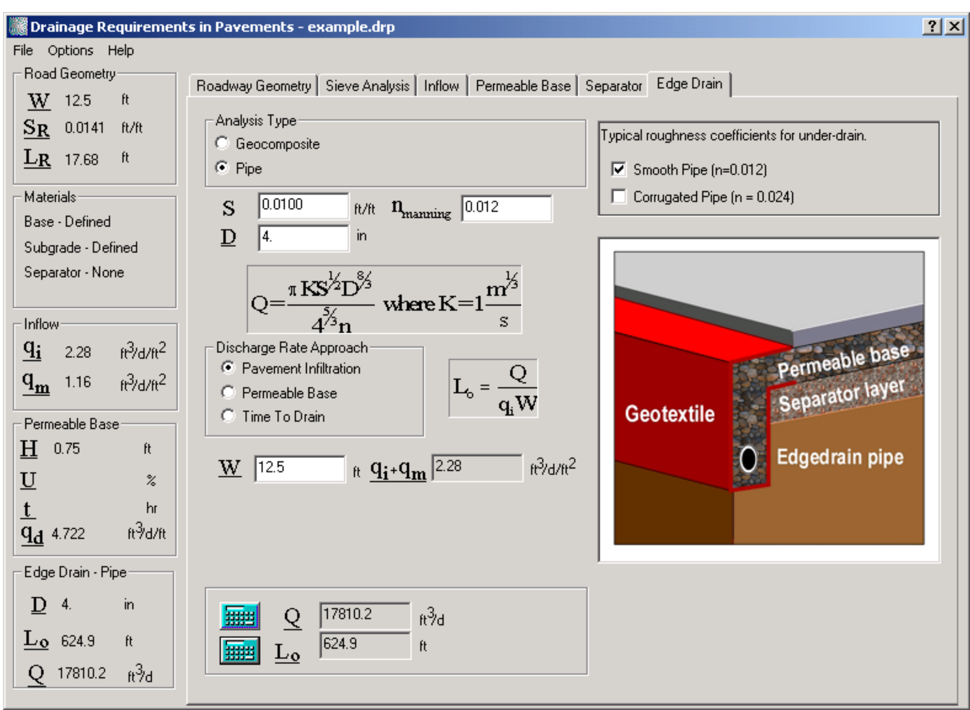


Figure 34. Edgedrain (pipe edgedrain) property page.

Depth of Flow capacity of the permeable base. Finally, the *Time to Drain* approach is approach is based on the time required for a specific percentage of the water to drain from a saturated permeable base. Any of these approaches can be selected by clicking the appropriate radio button. When a discharge rate approach is selected in this manner, the equation that will be used to compute the outlet spacing is displayed on the screen. Edit boxes to enter values required to compute these parameters also appear on the screen. If the user has followed the suggested design flow, values will have already been provided for each parameter used. Therefore, the user can quickly calculate the required outlet spacing for each approach and compare the results.

The *Geocomposite Edgedrain* analysis screen, shown in Figure 35, differs mainly in the calculation of edgedrain capacity *Q*. For a geocomposite edgedrain, outlet pipe spacing L_o is actually a parameter used in the calculation of *Q*, along with slope *S* of the edgedrain, initial height of flow D_1, final height of flow D_2, and flow coefficient C_g. Thus, the calculation of the outlet spacing L_o is an iterative process. The program begins with an initial value of L_o of 100 m, calculates *Q*, then iteratively recalculates L_o. The process is repeated until a result is converged upon.

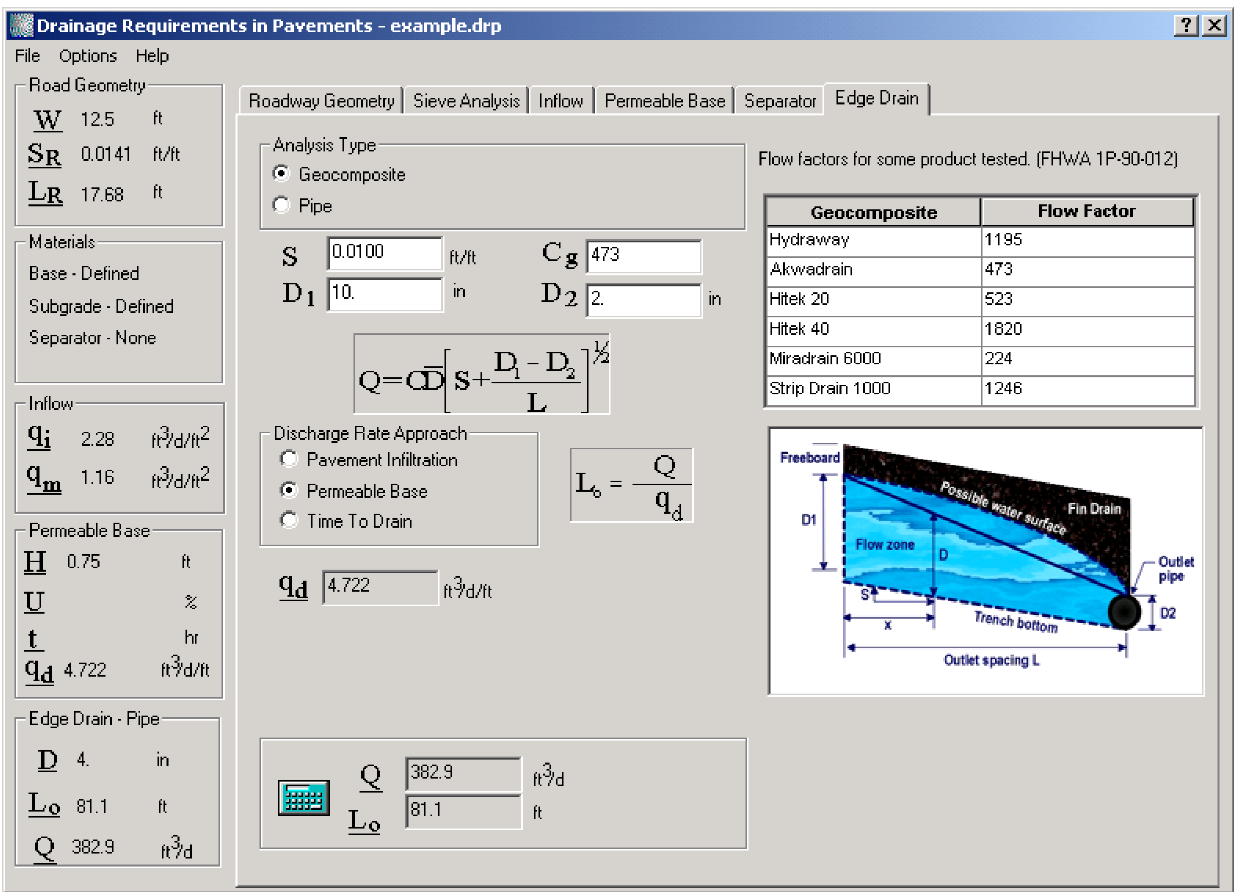


Figure 35. Edgedrain (geocomposite) property page.

A flowchart of the ***Edgedrain*** property page depicting the data flow in this screen is shown in Figure 36.

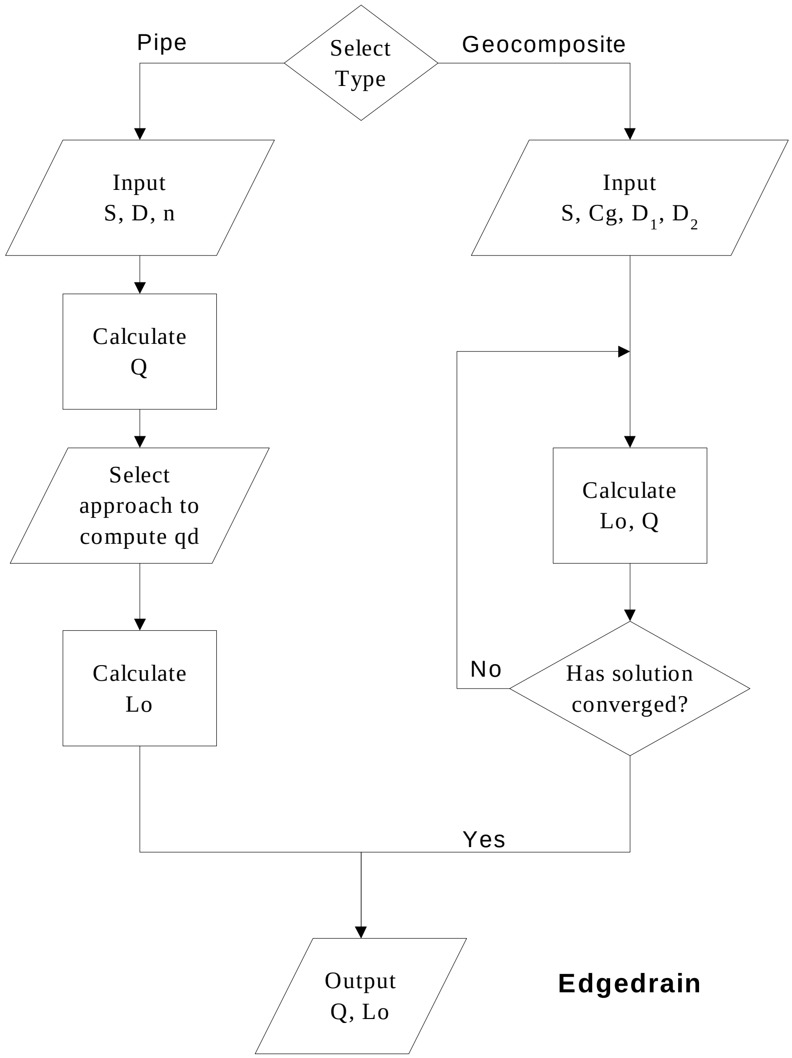


Figure 36. Flowchart for Edgedrain property page.

Project Summary

The two methods of obtaining analysis reports from DRIP are either to export the project summary using the *File | Export Summary* option or to print it using the *File | Print Summary* option. The format of exported summary file is HTML, and it can be viewed using any Web browser, spreadsheet, or word processing program. The steps involved in exporting and printing project summaries have already been outlined in the section dealing with DRIP menus. Since DRIP analyses are modular in nature, the summaries provided are also divided into subsections—Roadway Geometry, Sieve Analysis, Inflow, Permeable Base, Separator, and Edgedrain. A summary for a particular subsection is output only if data has been entered for that analysis or that analysis has been completed. If no data has been entered, only the primary header of that analysis module is provided.

5.0 EXAMPLE PROBLEMS

This section contains sample exercises that acquaint the user with the operation of DRIP. These examples also illustrate how to perform hydraulic design using DRIP. As noted in PART 3, Chapter 1, drainage analysis and design should be considered as a first step in structural design. The DRIP program is also useful to determine air voids and effective grain sizes for a given gradation, which are important materials inputs to the 2002 Design Guide software. The examples presented below will also explain how to perform these calculations.

Example Problem Number 1

Given

A pavement section consists of two 12-ft lanes of 9-in-thick PCC pavement with 10-ft AC shoulders on each side with a uniform cross slope (not crowned), and the width of the permeable base is the same as the PCC pavement. The transverse joint spacing is 20 ft. The slope in both the longitudinal (S) and transverse (S_x) directions is 2 percent. The permeable base is made up of AASHTO #57 material and has a unit weight of 100 pcf, specific gravity of 2.65, and a minimum permeability of 3000 ft/day. The thickness of the permeable base is 4 in, based on construction considerations. Assume a unit weight of 162 pcf for the PCC material. The subgrade is Georgia Red Clay, which is actually a well-graded clayey-silt. Laboratory tests indicate the particle gradation shown in Table 1 for the subgrade material and a permeability of 0.0033 ft/day. Corrugated pipe edgedrains having 4-in diameter are used on the project.

Table 1. Sieve analysis of Georgia Red Clay subgrade.

Sieve No.	Percent Passing
# 4	92
#10	67
#20	55
#50	42
#200	31

Determine

Use the crack infiltration method to determine inflow. Check the adequacy of the permeable base using the depth-of-flow approach to determine flow conditions. Determine the need for an aggregate separator layer and the adequacy of the 4-in pipe.

Solution

Prior to starting the analysis, the user needs to select the type of units in which to perform the analysis. This problem will be solved using English units. This system of units is the default option in DRIP and can be selected by checking English under the *Options | Units* menu command. Once selected, this system of units will be retained throughout the analysis unless the user makes a change. Similarly, the mode of program execution (Expert or Normal) can also be selected from the *Options* menu. The default is the Normal mode, and that will be used in this example.

The problem solution is presented under several different sections. The arrangement of these sections follows the logical left-to-right approach emphasized earlier. An experienced user may, however, solve the problem using a different sequence of steps.

Pavement Geometry

Step 1: Select the ***Roadway Geometry*** tab (this is the default program tab) to access the corresponding property page. Select a uniformly cross-sloped pavement section by clicking on the Geometry B radio button.
Step 2: Enter the value of b as 24 ft (2 lanes of 12 ft each). Since the problem statement assumes that the width of the permeable base is same as that of the PCC layer, enter the value of c as 0. Clicking the calculator icon for width of the permeable base W results in a computed value of 24 ft.
Step 3: Enter the longitudinal and transverse slopes in the S and S_X edit boxes, respectively. Click the calculator icons for both S_R (resultant slope) and L_R (resultant length) to compute these parameters. The calculations should yield the following values: S_R = 0.0283 ft/ft and L_R = 33.94 ft/ft.

The completed screen is shown in Figure 37. The values entered and computed in this property page will be saved and carried forward for later use. Note that as soon as the computations are completed on this page, the respective values are displayed on the left side of the main DRIP client window. This screen can be exited by clicking on another tabbed property page.

Inflow Computation (Crack Infiltration Method)

Step1: Select the ***Inflow*** tab to access the corresponding property page. Click on the Crack Infiltration Method radio button (since this method was required to be chosen to estimate inflow).
Step 2: Retain the default values of 2.4 ft^3/day/feet for I_c and 0 for pavement permeability k_p. Also retain the values for W_c and W that have been automatically carried forward from the calculations performed on the ***Roadway Geometry*** page.
Step 3: Enter the number of longitudinal cracks, N_c, as 3 (N_c = the number of contributing lanes + 1 = 2 + 1 = 3). Enter the given transverse spacing of contributing transverse joints C_s = 20 ft.

Step 4: Click the calculator icon to compute inflow q_i. This should yield a value of 0.42 $ft^3/day/ft^2$.

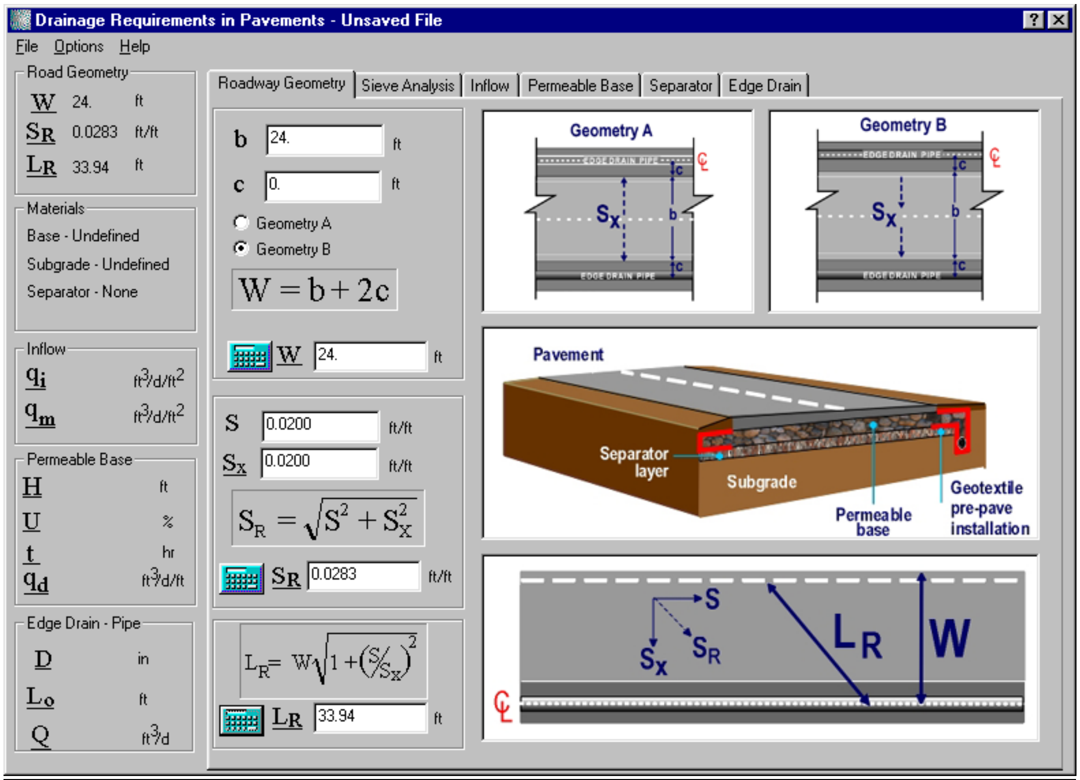


Figure 37. Computation of roadway geometry.

The values entered and computed in this screen will be stored and carried forward to other screens where they are needed. The completed ***Inflow*** screen is shown in Figure 38. The computed inflow value is updated in the summary page.

Meltwater Computation

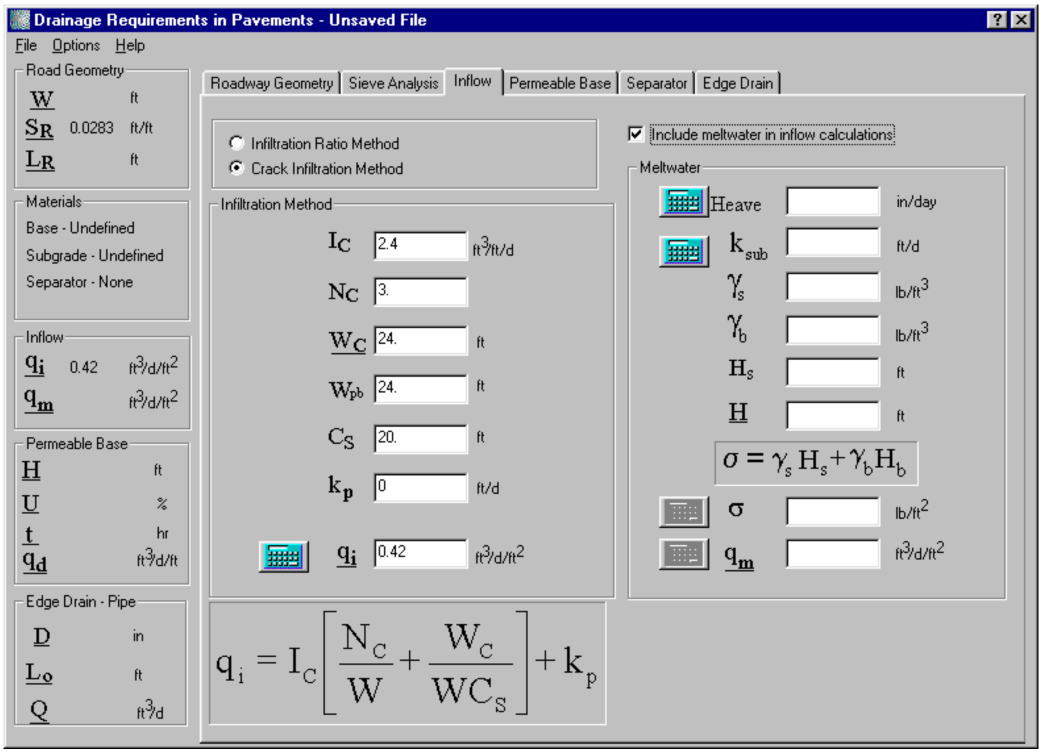
Step 1: Activate the *Meltwater* sub-screen in the ***Inflow*** property page by clicking on the "Include Meltwater in the inflow calculations" checkbox.

Step 2: The heave rate (*Heave*) for the clayey-silt subgrade soil can be determined by clicking on the calculator button located to the left of the variable. This action calls up the heave rate table. The heave rate table shows that the value for clayey-silt soil is 0.51 in/day. This value can either be entered manually in the edit box on the *Meltwater* sub-screen or entered automatically by selecting the row corresponding to clayey-silt soil type.

Note : For materials with large heave rates, the mid-point values may be entered.

Step 3: Enter the given values for the subgrade permeability (k_{sub} = 1 ft/day), unit weight of the pavement surface (γ_p = 162 lb/ft^3), the unit weight of the base material above the subgrade (γ_b = 100 lb/ft^3), the thickness of pavement surface (H_s = 9 in.), and the thickness of the base material (H = 4 in.) in the appropriate boxes.

Step 4: Click on the calculator icon next to the variable σ to compute the stress imposed by the pavement on the subgrade. This will yield a value of 154.8 lb/ft^2.



$$q_i = I_C \left[\frac{N_C}{W} + \frac{W_C}{WC_S} \right] + k_p$$

Figure 38. Crack infiltration computation.

Step 5: Click the calculator icon for determining the quantity of meltwater (q_m). Moulton's meltwater chart appears on the screen. On this screen a horizontal red line appears marking the heave rate of the subgrade (0.51 in/day). Use the mouse to slide the vertical tick line along the horizontal red line (0.51 in/day line) to an approximate location for a stress of 154.8 psf. The value for $q_m/(k_{sub})^{0.5}$ will appear in the appropriate box. When satisfied that the mouse is positioned at the proper stress value, click the left mouse button to produce a computed value of q_m. For this example, the mouse is positioned to indicate a value of $q_m/(k_{sub})^{0.5}$ of 0.91 ft^3/day/ft^2. A click of the left mouse button produces a value for q_m of 0.05 ft^3/day/ft^2. Press OK to return to the ***Inflow*** property page.

The values entered and computed in this screen will be retained and carried forward. The Moulton's meltwater chart is shown in Figure 39, and the completed meltwater screen is shown in Figure 40. The computed meltwater quantity (q_m) is updated in the summary page.

Permeable Base Design (Depth-of-Flow)

Step 1: Select the ***Permeable Base*** tab to access the corresponding property page. Click on the Depth of Flow Method radio button. Most of the variables such as q_i+q_m, S_R, L_R, and H already have values carried forward from pervious screens.
Note: The term q_i+q_m is a summation of the inflow from rainfall and meltwater.

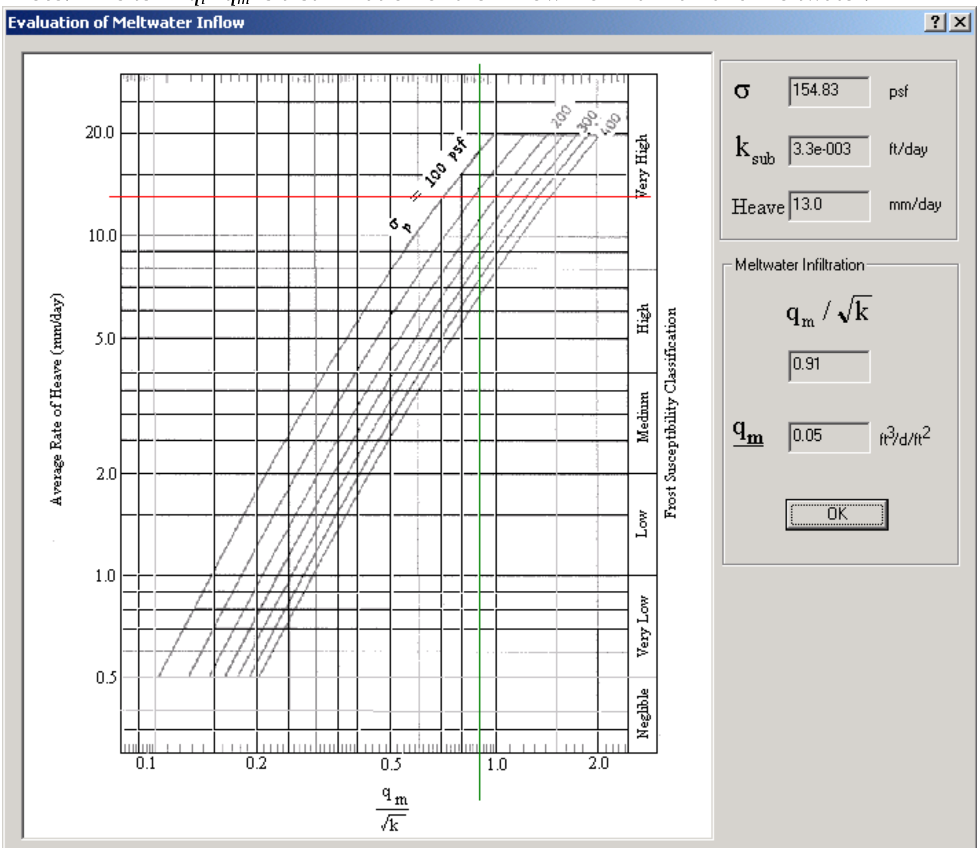


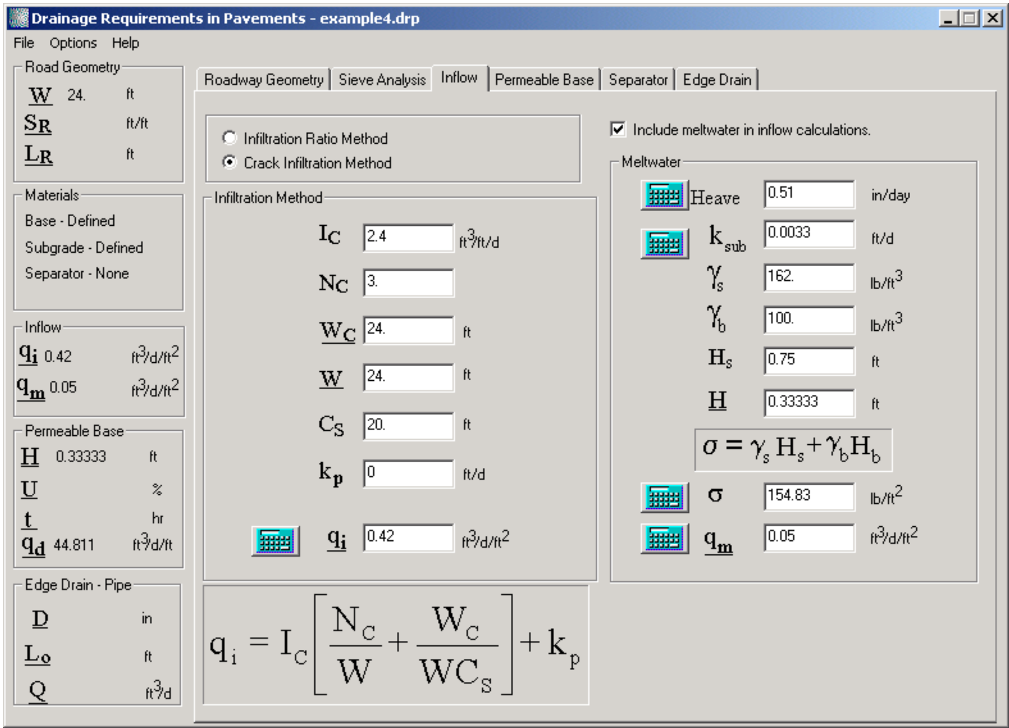
Figure 39. Moulton's meltwater chart.

Step 2: Enter the coefficient of permeability of the base (k = 3000 ft/day).

Step 3: Compute the H_{min} by clicking on the calculator icon. A H_{min} value of 0.1437 ft is reported, which is lower than the selected permeable base thickness (H) of 0.3333 ft. Therefore, the design is satisfied.
Note: If Hmin were much greater than H, the designer would make adjustments to the design by changing design variables such as base thickness or permeability. If the base thickness H can be revised, this parameter must be changed to be at least equal to the Hmin.

Step 4: Compute flow capacity of the permeable base (q_d) by clicking on the appropriate calculator button. This yields a value of 44.811 ft^3/day/ft. The flow capacity is estimated from Moulton's chart.

A completed design screen for the depth-of-flow design is shown in Figure 41. The values computed here are carried forward to other screens. The summary box on the DRIP client window is also updated accordingly.



$$q_i = I_C\left[\frac{N_C}{W} + \frac{W_C}{WC_S}\right] + k_p$$

Figure 40. Meltwater computation.

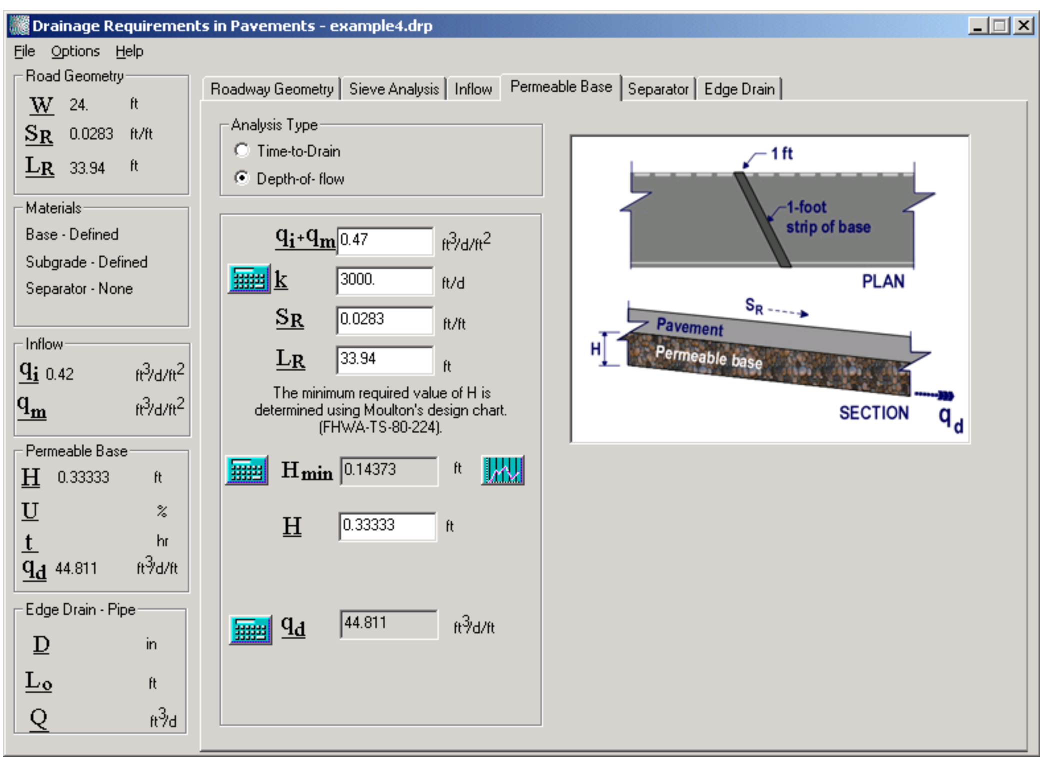


Figure 41. Permeable base depth-of-flow design.

Additional Discussion on Depth of Flow Design

If the user wishes to perform a sensitivity analysis to see the influence of different parameters on the required thickness, the graph icon to the right of $H_{\min}$ variable in Figure 41 can be clicked. DRIP internally performs the calculations over a pre-selected range of the independent parameter (in this case the required base thickness) and computes andplots the dependent variables. The charts are plotted using the DripPlot. The DripPlot window appears as soon as the graph icon next to the H_{min} variable is clicked and the following sensitivity plots are displayed:

- Required Base Thickness (H_{min}) vs. Pavement Inflow (q_i or $q_i + q_m$).
- Required Base Thickness (H_{min}) vs. Base Course Permeability (k).
- Required Base Thickness (H_{min}) vs. Resultant Slope (S_R).
- Required Base Thickness (H_{min}) vs. Resultant Length (L_R).

The user can control the type of plots to be displayed in the DripPlot window using the *Options | Sensitivity* menu command prior to clicking the graph icon. An example sensitivity plot of required base thickness versus permeability is shown in Figure 42.

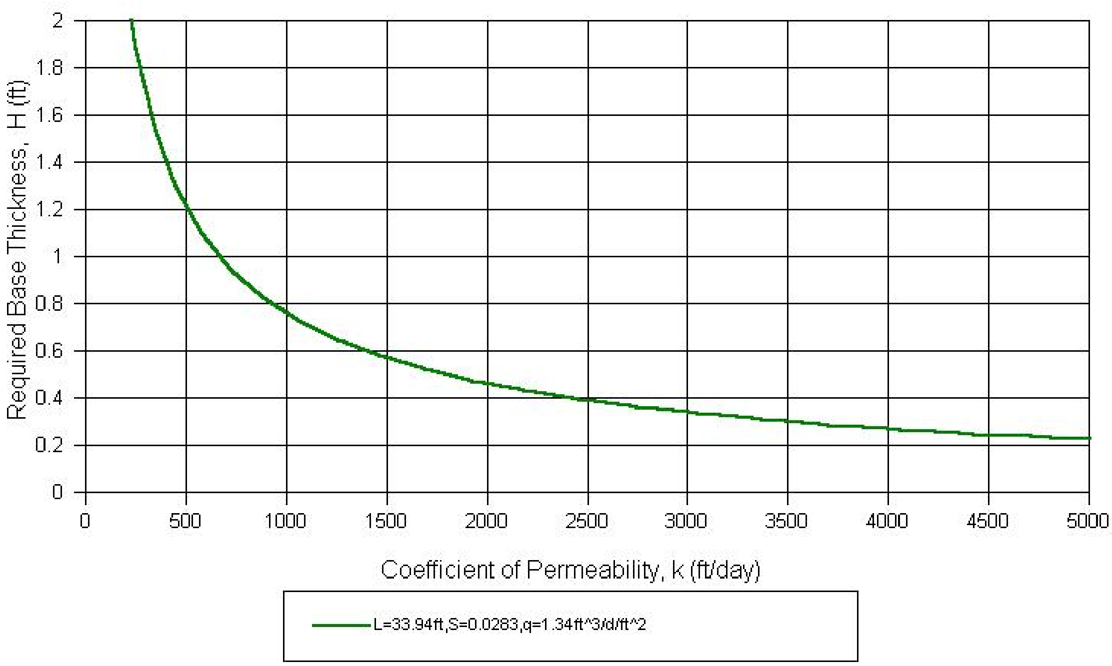


Figure 42. Depth-of-flow sensitivity analysis example (H vs k).

The generated plots can be directly saved as image files (jpeg or dib formats) using the appropriate options under of the *File* menu. Hard copy outputs can also be generated using the *File | Print* command or using the printer icon on DripPlot.

Separator Layer Design

Step 1: Select the ***Separator Layer*** tab. Select the No Separator radio button to evaluate the need for a separator layer.

Step 2: Click on the calculator icon next to the *Base Course* variable. This shifts the user to the ***Sieve Analysis*** property page. The permeable base is made up of the AASHTO #57 material. The gradation for this material is already in the sieve analysis library. To initialize this gradation to the program, click on the drop-down material library list box and select AASHTO #57. Click on the calculator icon to determine the particle sizes for D_{15} and D_{50}.

Step 3: Select the ***Separator Layer*** tab again. The values of D_{15}=0.2529 in. and D_{50}=0.5484 in. appear for the *Base Course.*

Step 4: Click on the calculator icon next the *Subgrade* variable to compute the subgrade particle sizes. The user is returned to the ***Sieve Analysis*** property page again and the Subgrade radio button is automatically activated. Select the Value radio button and enter the subgrade gradation in the grid on the left-hand side of the property page. Compute the D_{50} and D_{85} by clicking on the particle size calculator icon.

Step 5: Return to the separator layer property page by selecting the ***Separator*** tab. The values of D_{50}=0.0253 in. and D_{85}=0.1498 in. are returned for the subgrade.

Step 6: On the ***Sieve Analysis*** property page, check the filtration and uniformity criteria at the subgrade/base interface by clicking on the balance icon on the right-hand side. Both the criteria generate a *Pass* rating, which implies that no separator layer is required.

The completed separator layer screen is shown in Figure 43. Note that the summary page on the right side of the DRIP screen shown in the figure now states that the base and subgrade materials have been defined.

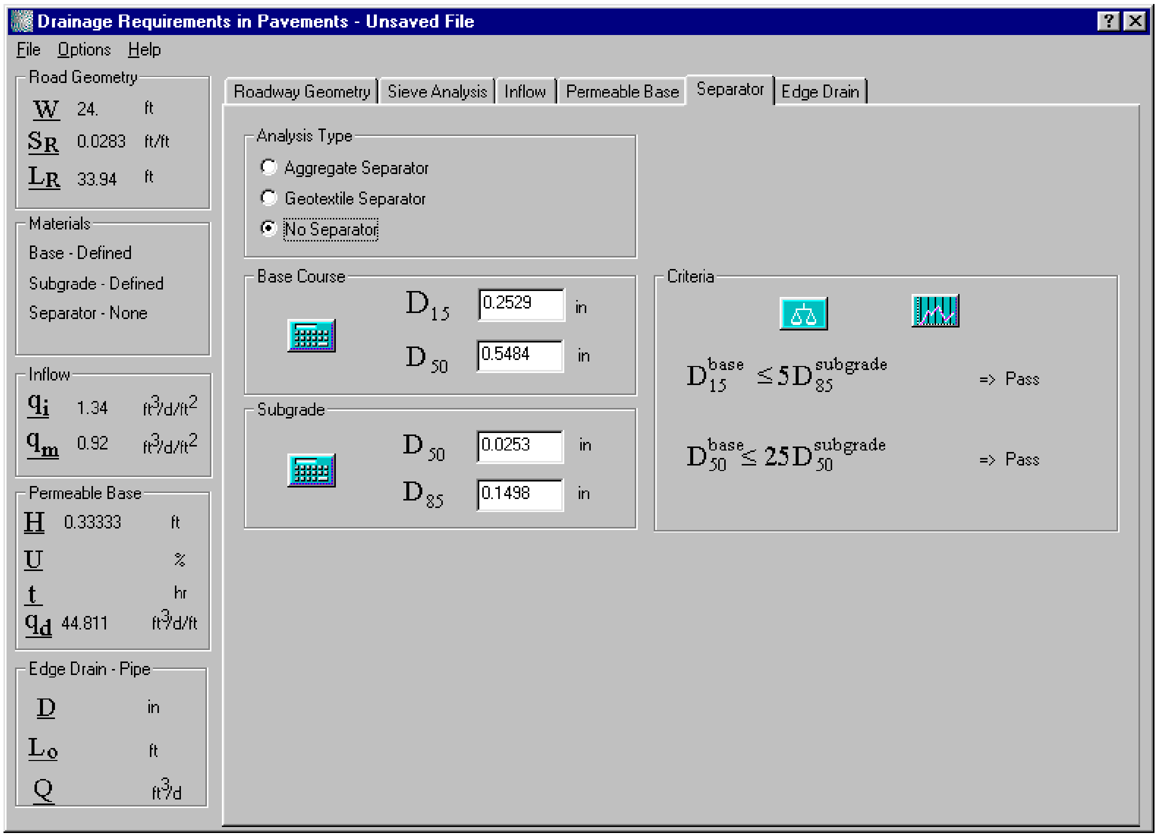


Figure 43. Checking separation criteria.

Edgedrain Design

Step 1: Select the ***Edgedrain*** tab.

Step 2: Select the Pipe Edgedrain radio button. Click the "Corrugated" checkbox and a value of $n_{manning}$ = 0.024 is displayed. Type in a value of D = 4 in.

Step 3: The calculator icon is enabled for calculating the pipe capacity (Q). The computed pipe capacity should read 12,594 ft^3/day.

Step 4: Click on the L_o button to compute the outlet spacing. This gives an L_o value of 391.6 ft. However, this value is based on the default selection of the *Pavement Infiltration* method for the pavement discharge rate (see under "Discharge Rate Approach" option list). Two other methods are given to compute the maximum outlet spacing: *Permeable Base* and *Time-to-Drain*. Since the time-to-drain method was not used for designing the permeable base we will not examine this approach. For computing the outlet spacing L_o based on the *Permeable Base* approach, select the appropriate radio button from the "Discharge Rate Approach" options. Our previously computed base discharge q_d of 44.81 ft^3/day/ft appears automatically. This results in a maximum outlet spacing of 281 ft. Thus, the permeable base discharge result is the critical value, so the user should specify an outlet spacing of 281 ft.

The final edgedrain design screen is shown in Figure 44. Note the updated summary on the left side of the screen shown in the figure. A printed output summary can be obtained by clicking on *File* | *Print Summary* menu option.

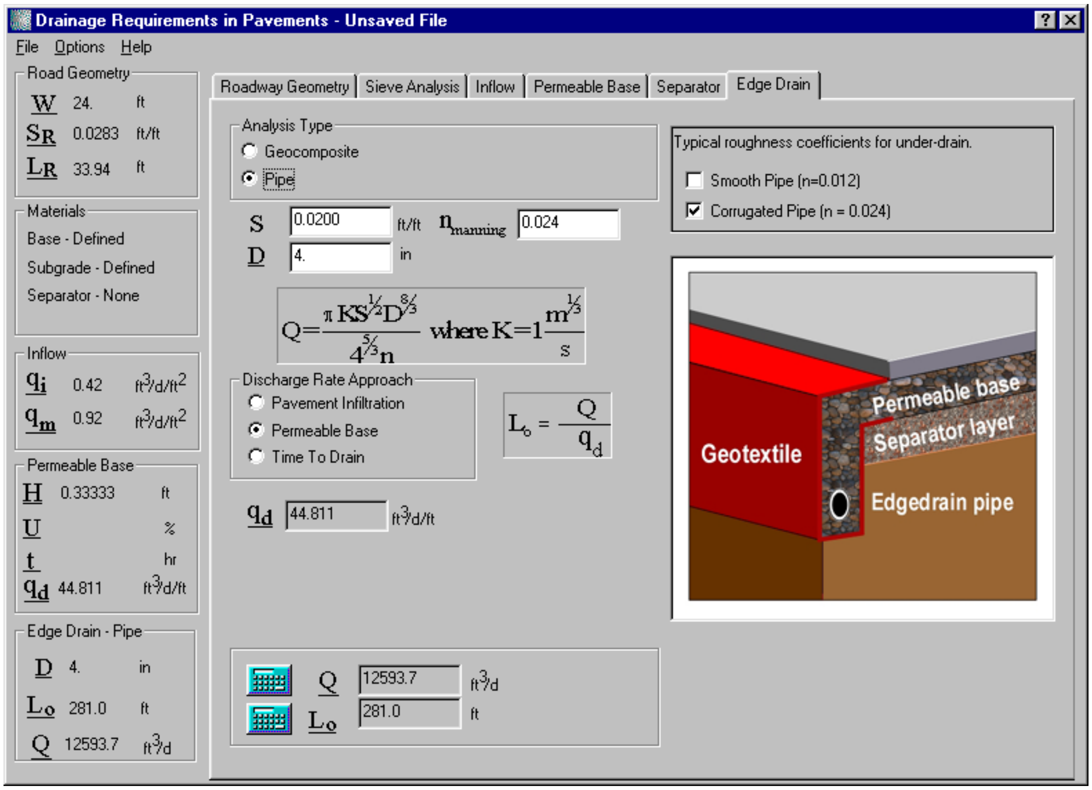


Figure 44. Pipe edgedrain design and outlet spacing computation

Example Problem Number 2

Given

The input data are the same as Example Problem No. 1, except that a woven geotextile is used for the separator layer and a Hydraway geocomposite edgedrain is present. Permeability conditions are critical.

Determine

Calculate the time to drain of the permeable base. Design the geotextile separator layer. Calculate the outlet spacing for the geocomposite edgedrain.

Note: The roadway geometry and inflow calculations do not have to be performed again.

Solution

Sieve Analysis

Step 1: Click on the ***Sieve Analysis*** tab in the DRIP client window. Select the Base radio button. The AASHTO #57 gradation configured in the previous example should appear automatically in the grid on the left side of the screen.

Step 2: Enter the given values for the *Unit Weight* (130 pcf) and *Specific Gravity* (2.65) of the base.

Step 3: Compute the porosity $n = 0.214$ by clicking on the calculator icon.

Step 4: Select the Water Loss Method radio button to compute the effective porosity. This selection is justified since AASHTO #57 is a coarse gradation. Immediately, the "Water Loss" table pops up. On this screen, an extrapolated passing # 200 value of 0.5% is displayed. Select the Silt radio button for the type of fines. This produces a Water Loss value of 76% for gravel. Select this value with a cursor and click OK to transport this value to the ***Sieve Analysis*** screen.

Step 5: Click on the calculator icon adjacent to the effective porosity n_e on the ***Sieve Analysis*** screen to compute this value. The program computes $n_e = 0.163$.

The final screen for computation of the permeable base material properties is shown in Figure 45.

Permeable Base Design (Time-to-Drain)

Step 1: Click on the ***Permeable Base*** tab to access the corresponding property page. Select the Time-to-Drain radio button. The values for the design inputs, n_e, k, S_R, L_R, and H should already be present from the analyses done as part of the previous example and this session so far.

Step 2: The time-to-drain factor t can be determined based on 50-percent drained or the 85-percent saturation criteria. The former is the more conservative for permeable bases, so it will be used. Enter U = 50%.

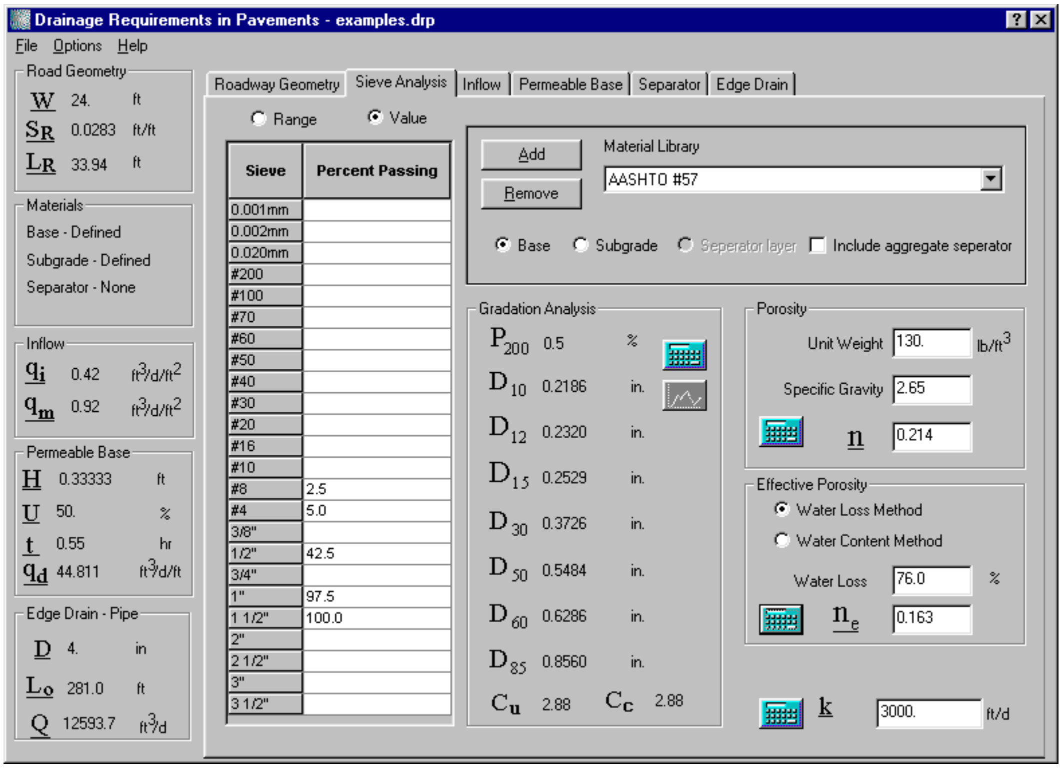


Figure 45. Performing particle size analysis of the permeable base.

Step 5: Click on the calculator icon adjacent to the variable *t* to compute it. A value of 0.55 hr is returned if the Barber/Sawyer equation is used (default). The Casagrande/Shannon equation yields a value of 0.52 hr. Both these results fit the "Excellent" drainage category.

The final ***Permeable Base*** design screen in shown in Figure 46.

Additional Discussion

Clicking on the graph icon to the right of the time to drain variable *t* generates the following sensitivity plots:

- Time to drain (*t*) versus Degree of drainage (*U*).
- Time to drain (*t*) versus Resultant length (L_R).
- Time to drain (*t*) versus Resultant slope (S_R).
- Time to drain (*t*) versus Coefficient of permeability of base (*k*).
- Time to drain (*t*) versus Base thickness (H).
- Time to drain (t) versus Effective porosity (ne).

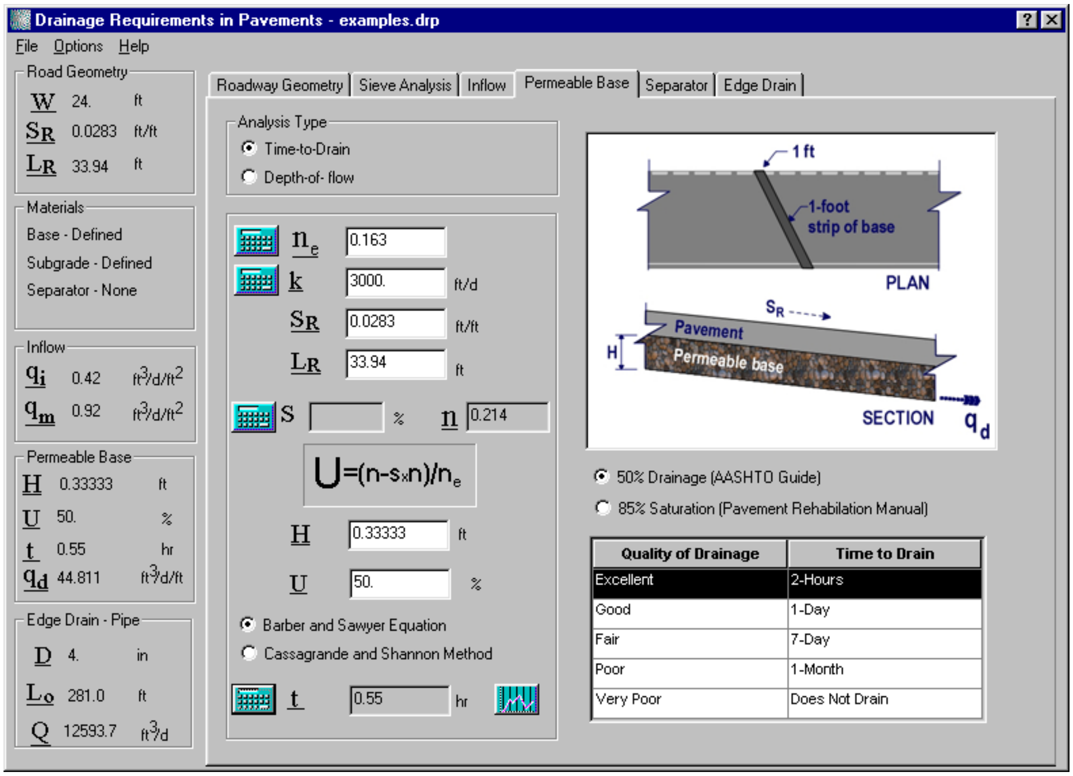


Figure 46. Time-to-drain computations for permeable base.

Separator Layer Design

Step 1: Click on ***Separator*** tab to access the property page. Click on the Geotextile Separator radio button.

Step 2: For conservatism, click the *Dynamic Flow* radio button for “Soil Retention Criteria.” Also, click the *Critical* radio button for permeability criteria.

Step 3: The P_{200}, k_{sub}, C_U, D_{15}, and D_{85} should be retained from the previous screen. If these values are not present, click on the calculator icon in the “Subgrade” category box, enter the Georgia Red Clay gradation, compute the particle sizes, D_{xx}, and C_U, and enter the given k_{sub} value. Then click on the ***Separator Layer*** tab to return to the separator layer property page.

Step 4: Once all the necessary computations are made, the separator property page should have the following values for the variables: P_{200} = 31%, k_{sub} = 1 ft/day, C_U = 211.73, and D_{15} = 5.88e-04 in, D_{85} = 0.1498 in. Click on the Woven Geotextile radio button in the “Geotextile Separator” category box. Click on the calculator icon to compute *AOS* = 0.0785 in. and *k* = 10 ft/day.

Step 5: Suppose a woven geotextile with *AOS* of 1/6 in. and a permeability of 100 ft/day can be found, type in k_{sep} = 100 ft/day. Click on the calculator icon to compute t_{max} = 0.069 in. for the geotextile. This is the maximum thickness of the geotextile. The percent open area should be equal or greater than 4 percent, as noted close to the bottom right of the screen.

Step 6: Finally, click on the balance icon on the right hand side of the screen to see if the chosen geotextile passes all the necessary criteria. All the criteria checks generate a *Pass* rating for the selected geotextile.

The final screen for the geotextile separator layer design is shown in Figure 47.

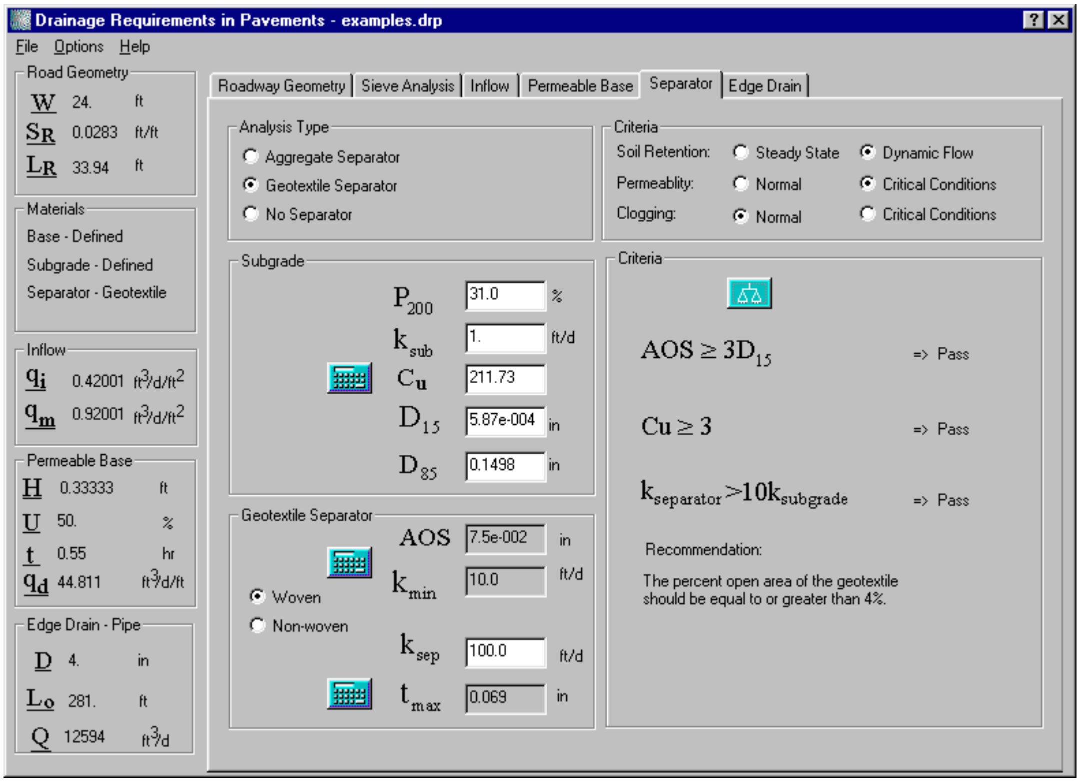


Figure 47. Geotextile separator layer design.

Edgedrain Design

Step 1: Click on ***Edgedrain*** tab to access the property page. Click on the Geocomposite radio button.

Step 2: Select the row for the Hydraway edgedrain from the table on the right side. The value of C_g = 1333 ft^3/day is automatically returned to the appropriate edit box.

Step 3: Type in a value of 12 in. for the height of flow zone D_1 and 4 in. for the diameter of the pipe D_2.

Step 4: Use the time-to-drain method for outlet pipe spacing by clicking on the Time-to-Drain radio button on the "Discharge Rate Approach" category box. All the necessary time to drain inputs should already appear in the respective variable edit boxes from the earlier computation on the ***Permeable Base*** screen.

Step 5: Click the calculator icon to compute Q and L_o. The program returns Q = 1691.1 and L_o = 59.4 ft.

The final screen for the geocomposite edgedrain design is shown in Figure 48.

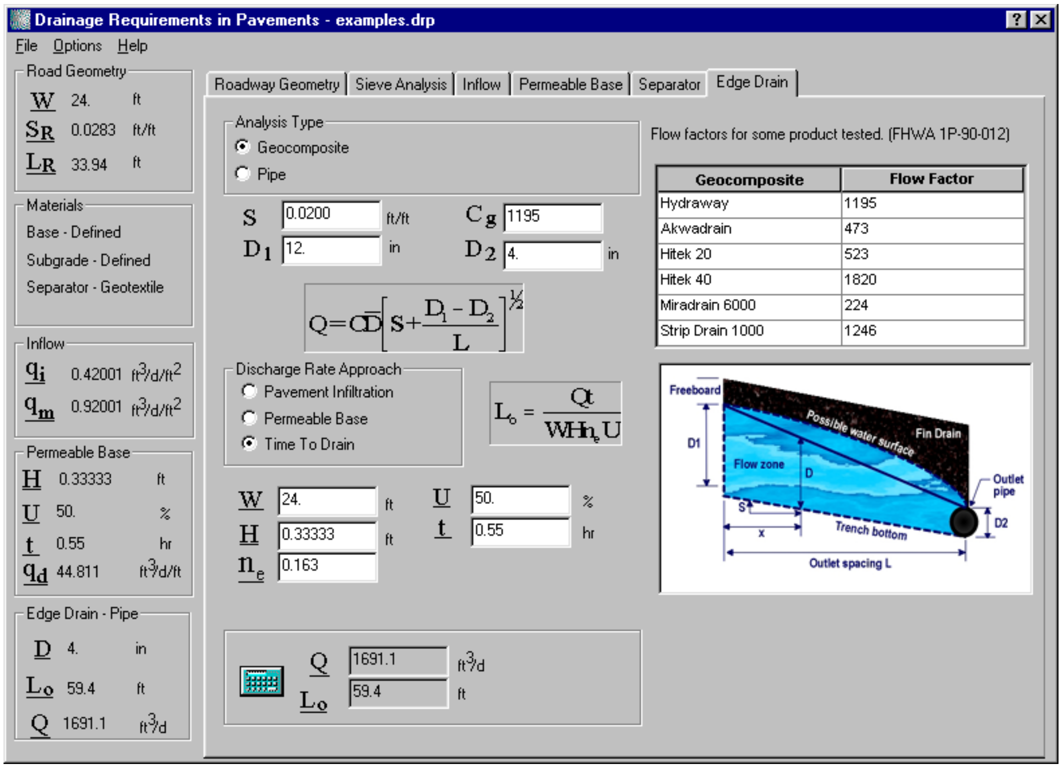


Figure 48. Design of geocomposite edgedrain.

Example Problem Number 3

Given

The gradations of a permeable base and a proposed aggregate separator layer to be used in a project are given in Table 2. Also given is the gradation of the subgrade soil at the project location.

Determine

Determine the need to place a separator layer between the permeable base and native subgrade. If there is a need, determine whether the proposed separator layer is adequate.

Solution

Step 1: Click on the ***Sieve Analysis*** tab to enter and store the given base, subgrade, and separator layer gradations.

Step 2: Click the “Include aggregate separator” check box.

Table 2. Gradations of pavement materials.

Sieve Sizes	Permeable Base	Subgrade	Proposed Separator Layer
1 1/2 in	100		
1 in	97.5		100
3/4 in			
1/2 in			85
3/8 in	70		
No. 4	47.5		65
No. 8	15	100	
No. 16	4		40
No 30		88	
No 40			
No. 50	2.5	68	
No. 100			
No. 200		45	11
0.001 mm (hydrometer)		4	

Step 3: To enter and save the gradation of the given permeable base, click on the *Base* radio button on the ***Sieve Analysis*** page. Enter the percent passing information for the permeable base given in Table 2 in the grid provided on the left side of the screen after selecting the *Value* radio button. After all the information is filled in, click on the “Add” button under the Material Library category box and save the entered gradation. Now, by clicking on the calculator icon under the Gradation Analysis category box, the user can compute the percent passing the No. 200 sieve, P_{200}, the particle sizes, D_{xx} (e.g., D_{10}, D_{12}, D_{15}), and the C_U and C_C values for the permeable base.

Step 4: Repeat the data entry and analysis performed in Step 3 for the separator and subgrade layers.

Step 5: Once all the gradations are entered and the corresponding properties computed, click on the ***Separator*** tab to access this property page. All the relevant D_{xx} values for each of the layers should already appear here. Under the separator layer property page select the No Separator option by clicking on the radio button. Then check the permeable base/subgrade interface by clicking on the balance symbol under the Criteria category box. The program indicates that the uniformity criterion has not been satisfied. This implies that a separator layer is required. Figure 49 displays the program screen generated from this calculation.

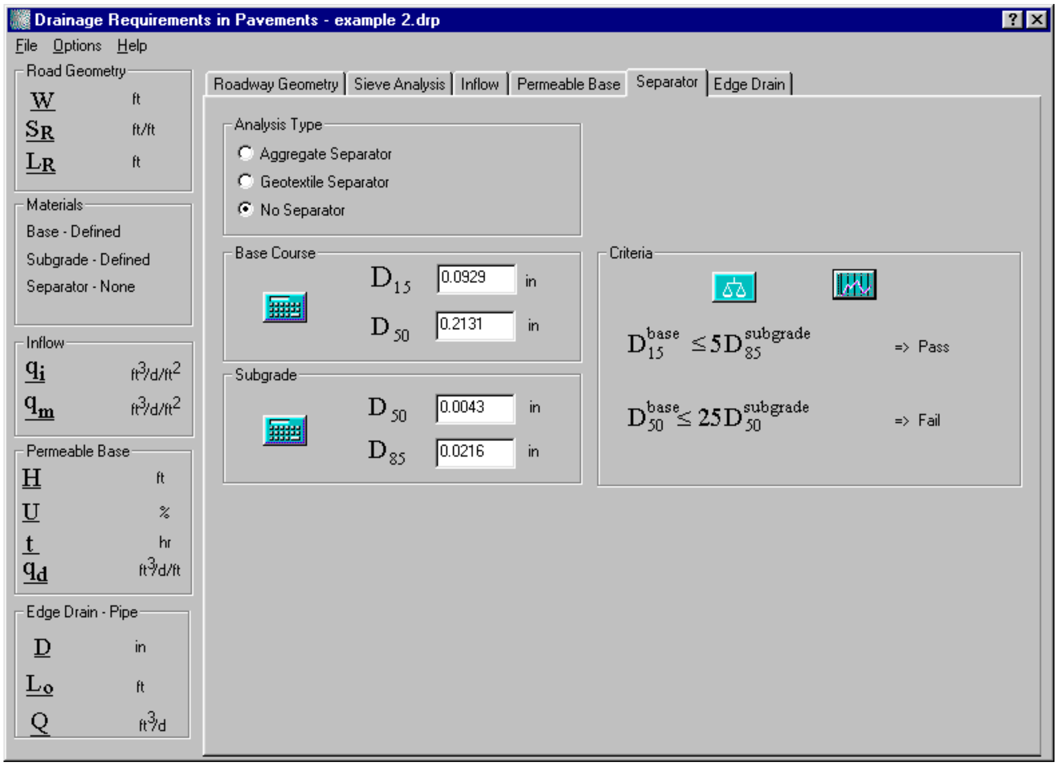


Figure 49. Final program screen for the No Separator option.

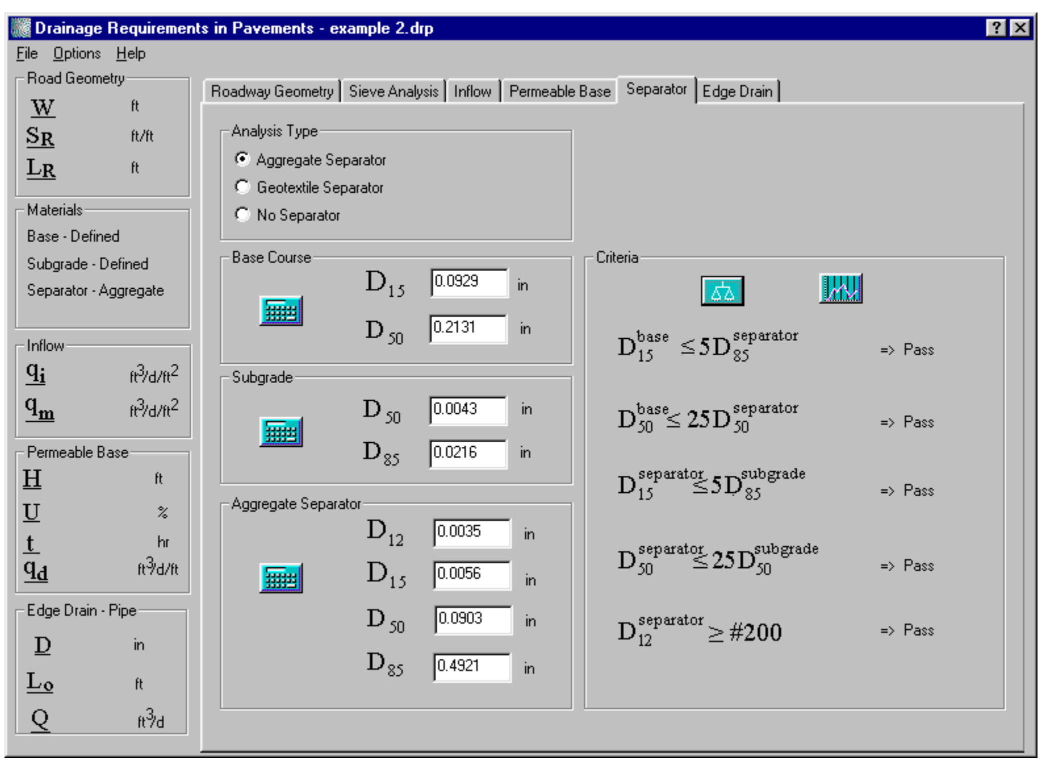


Figure 50. Final program screen for the Aggregate Separator option.

Step 6: Now choose the Aggregate Separator radio button. Check the criteria again by clicking on the balance icon. This results in the program generating a Pass rating for all the criteria. Therefore, the chosen separator layer is adequate. The final program screen for this computation is shown in Figure 50.

Step 7: A plot showing the gradations of the subgrade, permeable base, and the separator layer can be obtained by clicking on the graph icon next to the balance icon. On this plot, the upper and lower bounds of the gradation band within which the proposed separator layer has to fit to be considered acceptable also appear. These bounds are basically a graphical representation of the design criteria. The plot can be generated on a FHWA power 45 chart by selecting *Options | Plot Scale | Power 45* command from the Options menu. Alternately, selecting *Options | Plot Scale | Semi-log* command from the Options menu will result in a semi-log plot.

Figure 51 presents a gradation plot for the design example solved above on an FHWA power 45 chart. Figure 52 presents a semi-log plot of the same example in metric scale for comparison. Semi-log plots are useful in visualization when the gradations range from very fine to very coarse material. However, the D_{xx} values computed in DRIP are based on the power 45 charts.

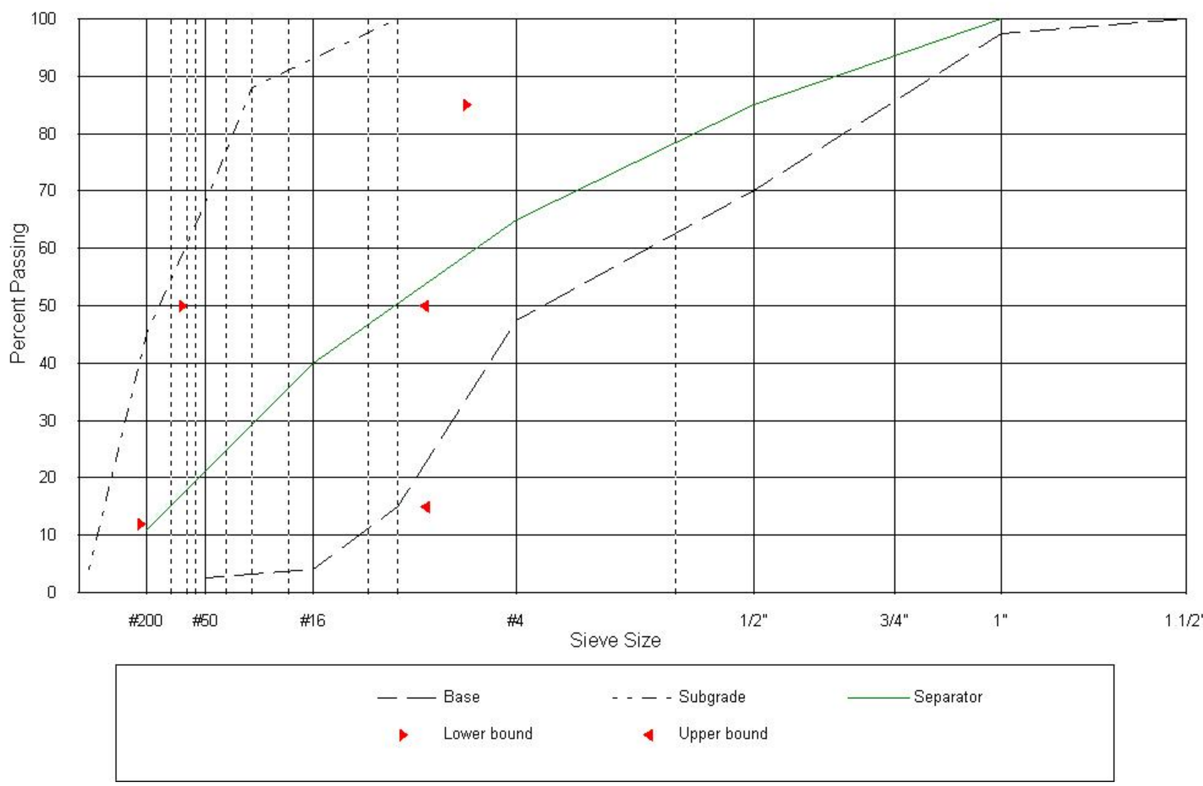


Figure 51. Separator layer design shown on an FHWA power 45 plot.

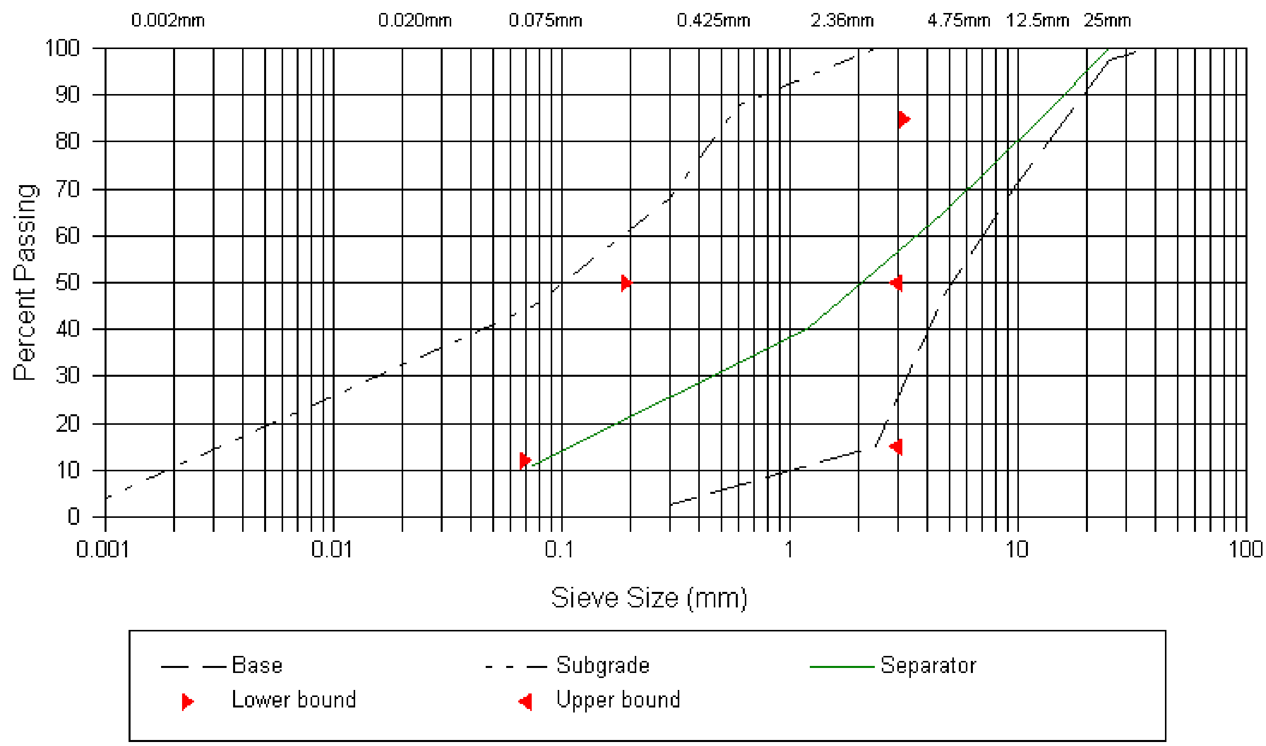


Figure 52. Separator layer design shown on a semi-log plot.

6.0 SENSITIVITY ANALYSIS

Time-to-Drain

The following plots were developed using the sensitivity plotting functionality of the ***Permeable Base*** property page for the time-to-drain method. The sensitivity plots presented here can be generated by the clicking the graph icon after the time-to-drain parameter *t* has been computed.

<u>Porosity</u>

In Figure 53 it can be seen that the effect of effective porosity is linear. This means that if the effective porosity is doubled, the time to drain is doubled. This is logical since twice the amount of water will be released from the base course. However, engineers should not yield to the temptation of reducing the effective porosity to reduce the time to drain. It must be remembered that the goal of drainage is to remove as much water as possible from the base course.

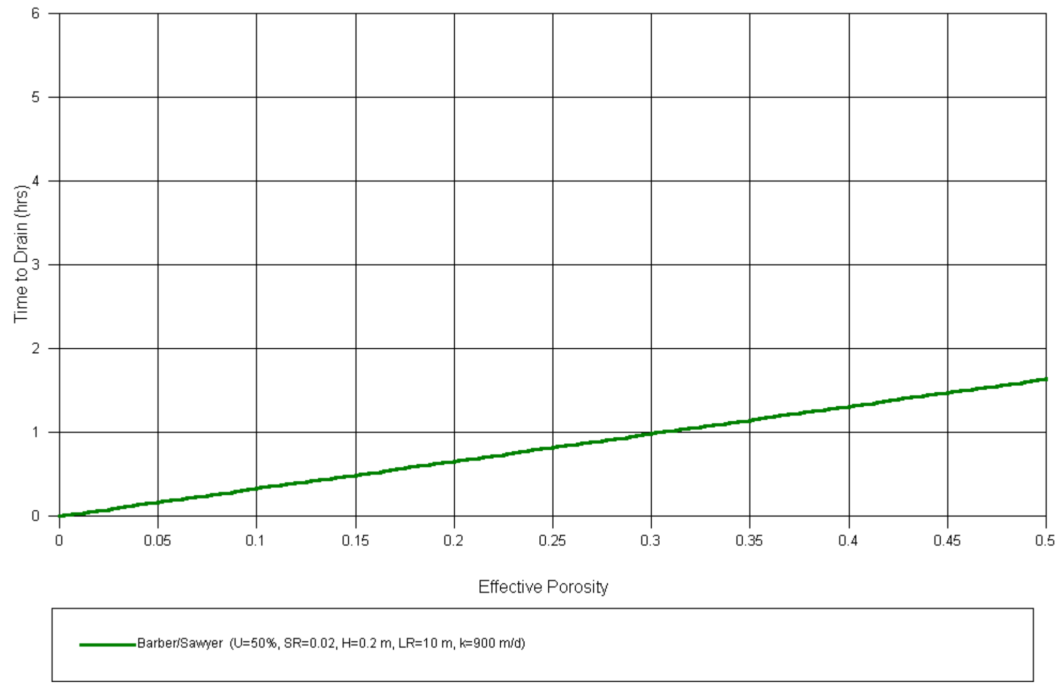


Figure 53. Time to drain versus effective porosity.

Permeability

In Figure 54, it can be seen that the effect of the coefficient of permeability is inversely proportional to the time to drain. The more permeable the material, the faster the base material will drain. Also, the effect of permeability on the time-to-drain parameter decreases with increasing permeability.

Resultant Slope

As shown in Figure 55, the design procedure is sensitive to the resultant slope, with the time to drain decreasing as the slope increases. This is logical; the steeper the slope, the faster water will drain. The time to drain continues to decrease over the entire range of slopes presented. Theoretically, the base will drain even if the slope is flat; however, it is questionable practice to apply the design procedure to flat slopes.

Resultant Length

Figure 56 shows the effect of resultant length of drainage path on the time-to-drain parameter. The relationship is quite linear in the reasonable range of L_R (4 m and greater).

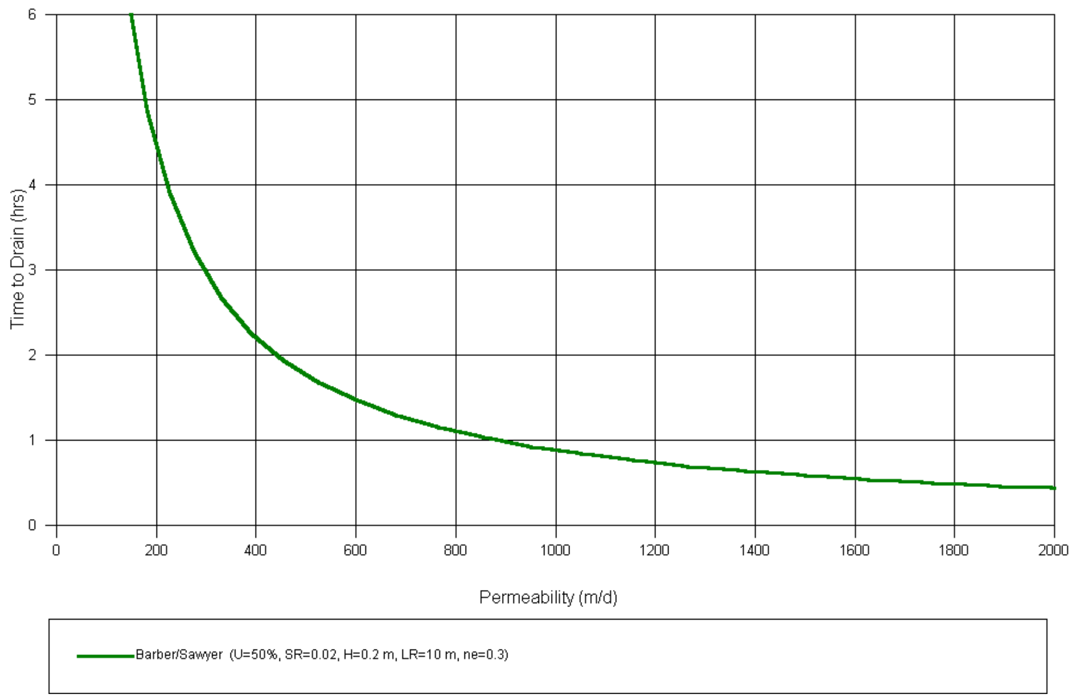


Figure 54. Time to drain versus coefficient of permeability.

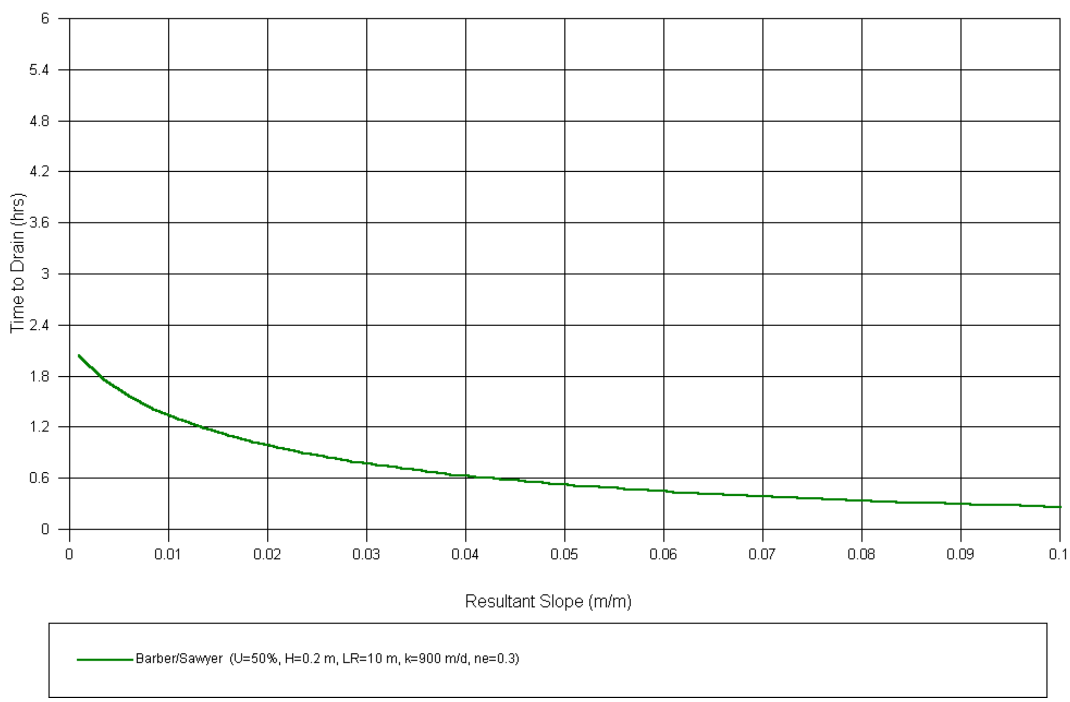


Figure 55. Time to drain versus resultant slope.

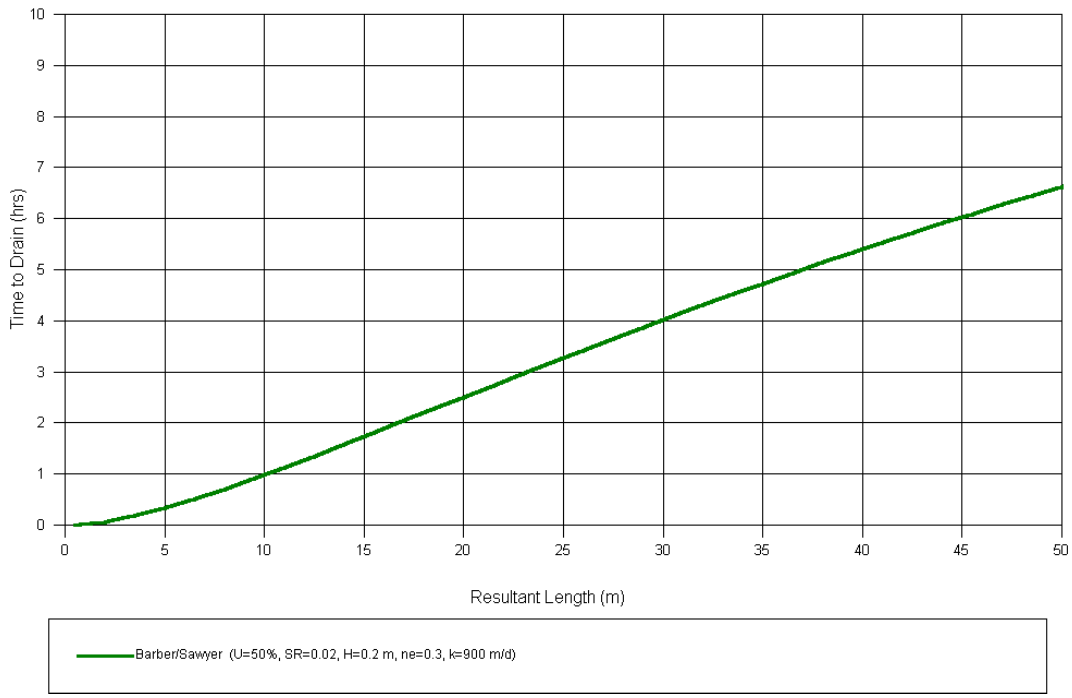


Figure 56. Time to drain versus resultant length of drainage path.

Thickness

The effect of base thickness is plotted in Figure 57. The time to drain is reduced by increasing the layer thickness. While there is large sensitivity to changes in *H* when the value is very small, the curve tends to reach a point where subsequent increases in *H* no longer have much effect on the time to drain.

Methodology

Figure 58 shows the recognizable plot of time to drain versus percent drainage for both the Casagrande/Shannon and Barber/Sawyer methods. Note that they are very similar, actually crossing each other at approximately U=55%. This is true in most cases.

The major difference in the two methods is shown in Figure 59, which plots time to drain versus base thickness for the same data set using each method. Note the wider variation at smaller values of *H*. For most reasonable values for base thickness, however, the two methods will yield similar results.

Base Thickness

The following plots were developed using the sensitivity plotting functionality of the ***Permeable Base*** screen for the *Depth-of-Flow* method. The sensitivity plots presented

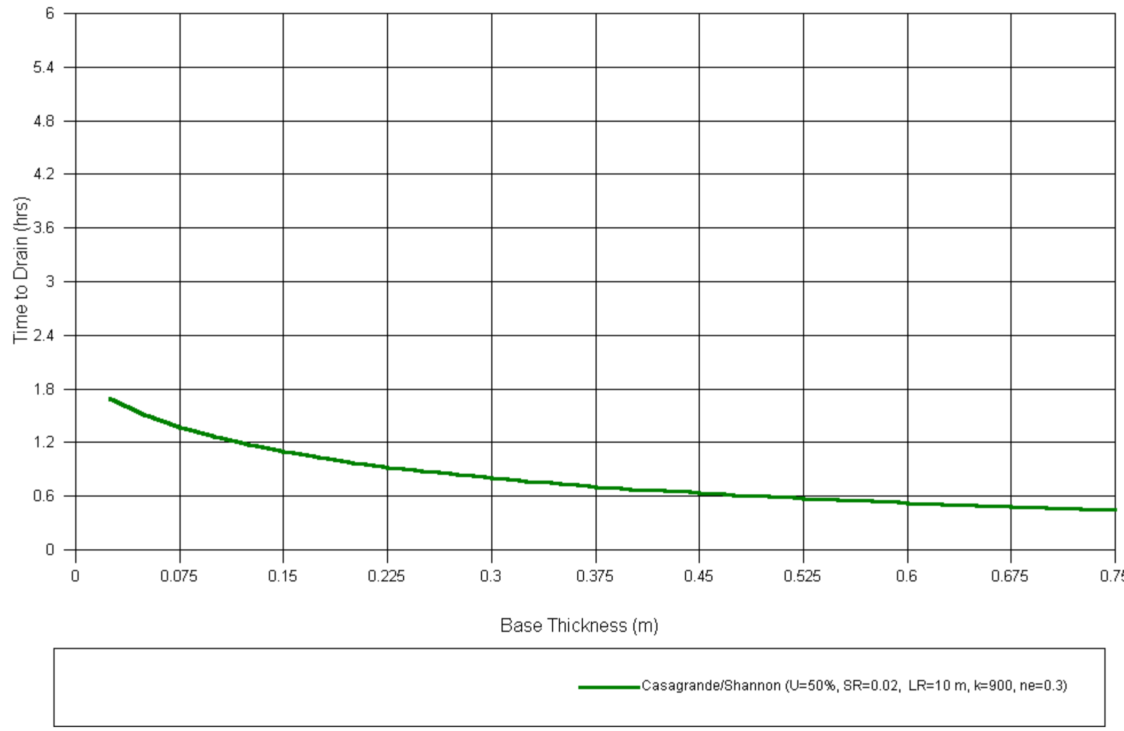


Figure 57. Time to drain versus thickness of permeable base.

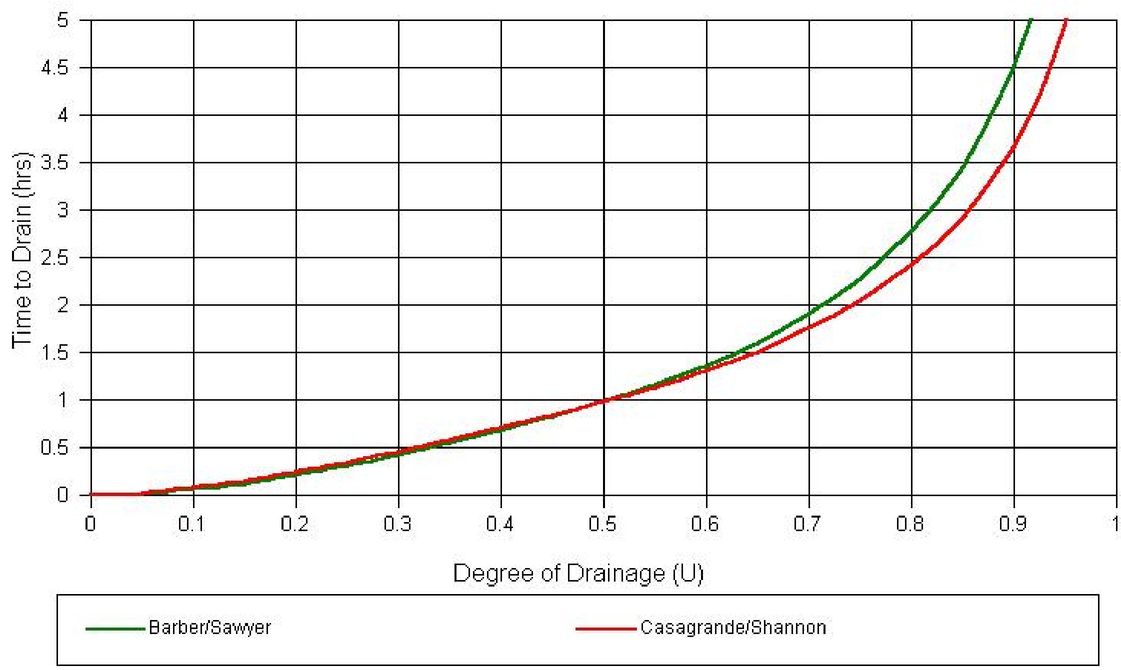


Figure 58. Time to drain versus degree of drainage for Barber/Sawyer and Casagrande/Shannon methods.

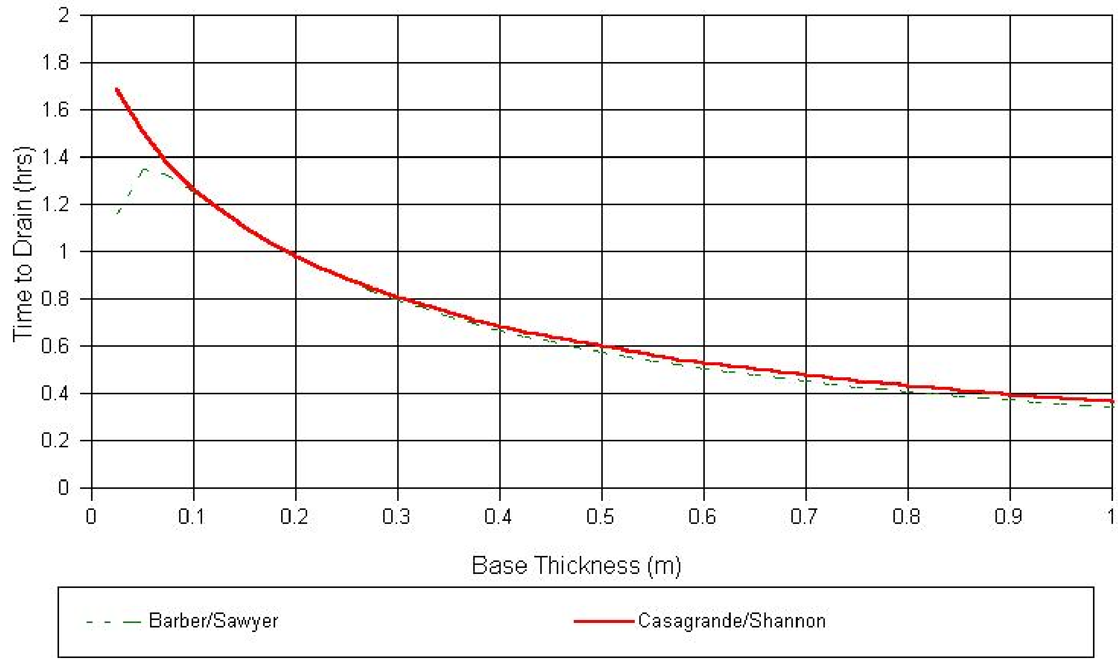


Figure 59. Time to drain versus base thickness using Casagrande/Shannon and Barber/Sawyer methods.

here can be generated by the clicking on the graph icon after the required minimum base thickness, Hmin, has been computed.

Permeability

In Figure 60, it can be seen that the effect of the coefficient of permeability is inversely proportional to the required minimum base thickness. As the permeability of the material increases, the base will drain faster and thus a thinner permeable base can be used. As the permeability increases, the required minimum base thickness decreases at a decreasing rate.

Resultant Slope

As shown in Figure 61, the design procedure is sensitive to slope with the required base thickness decreasing as the slope increases. As is the case for the time to drain, the flatter the slope, the slower the water will drain, and thus a thicker base is required to contain all the water. The depth required continues to drop over the entire range of slopes presented.

As was stated previously, the base will drain even if the slope is flat; however, it is questionable practice to apply the design procedure to flat slopes.

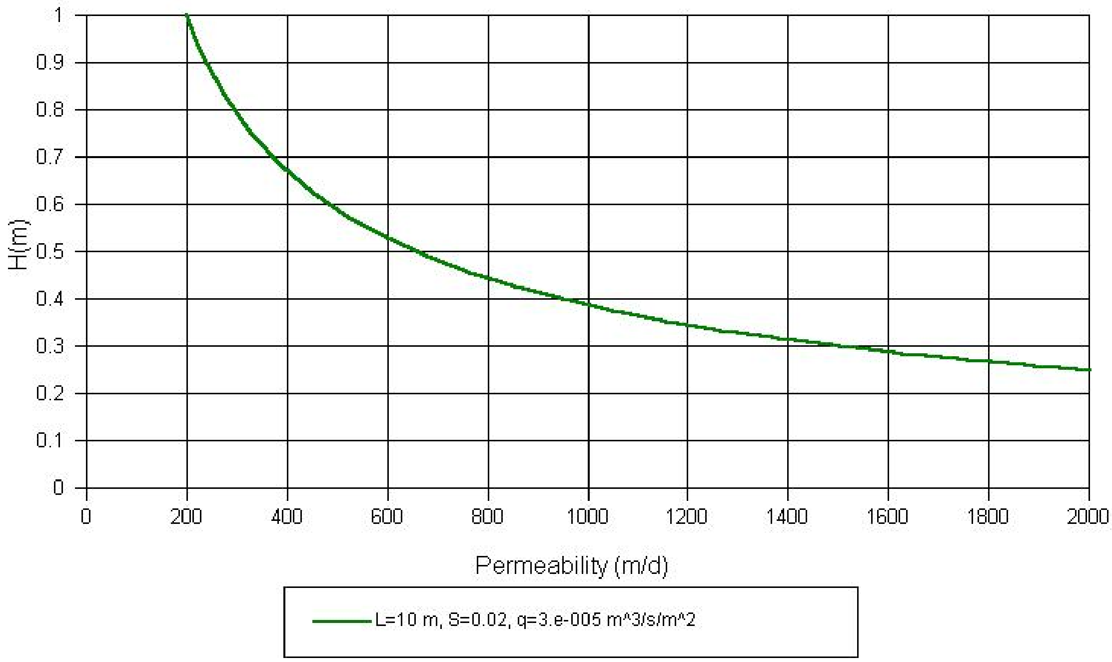


Figure 60. Minimum base thickness versus coefficient of permeability.

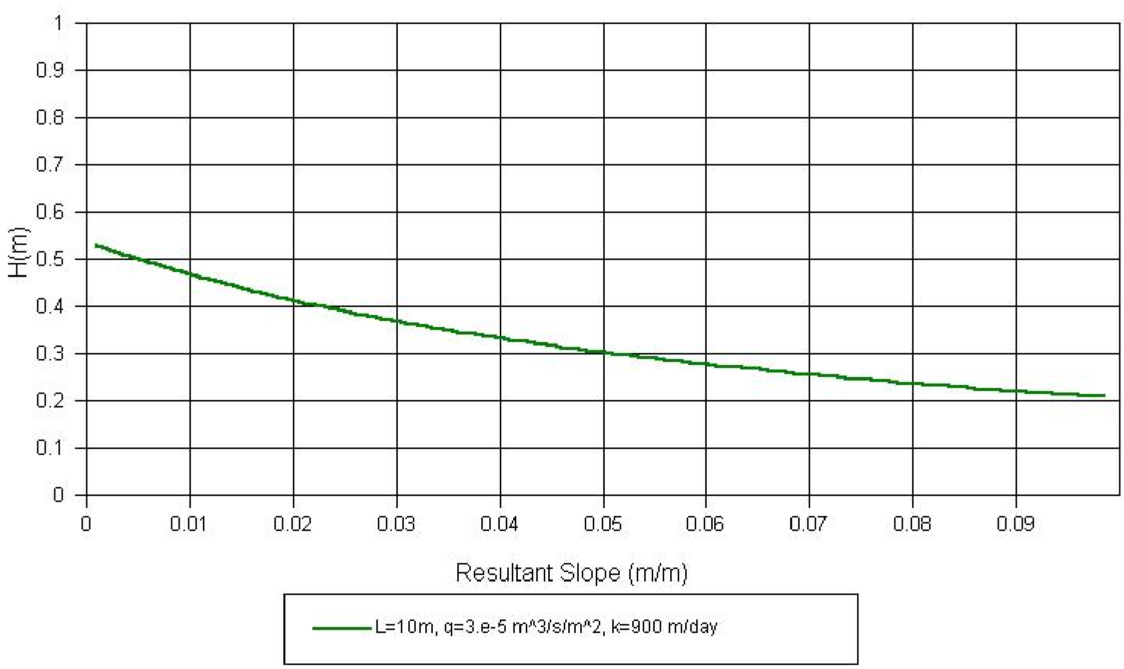


Figure 61. Minimum base thickness versus resultant slope.

Resultant Length

Figure 62 shows the effect of resultant length of drainage path. The relationship is linear, meaning that if the resultant length is doubled, the required base thickness is doubled. This is logical, since twice the amount of water will need to be contained in the base course.

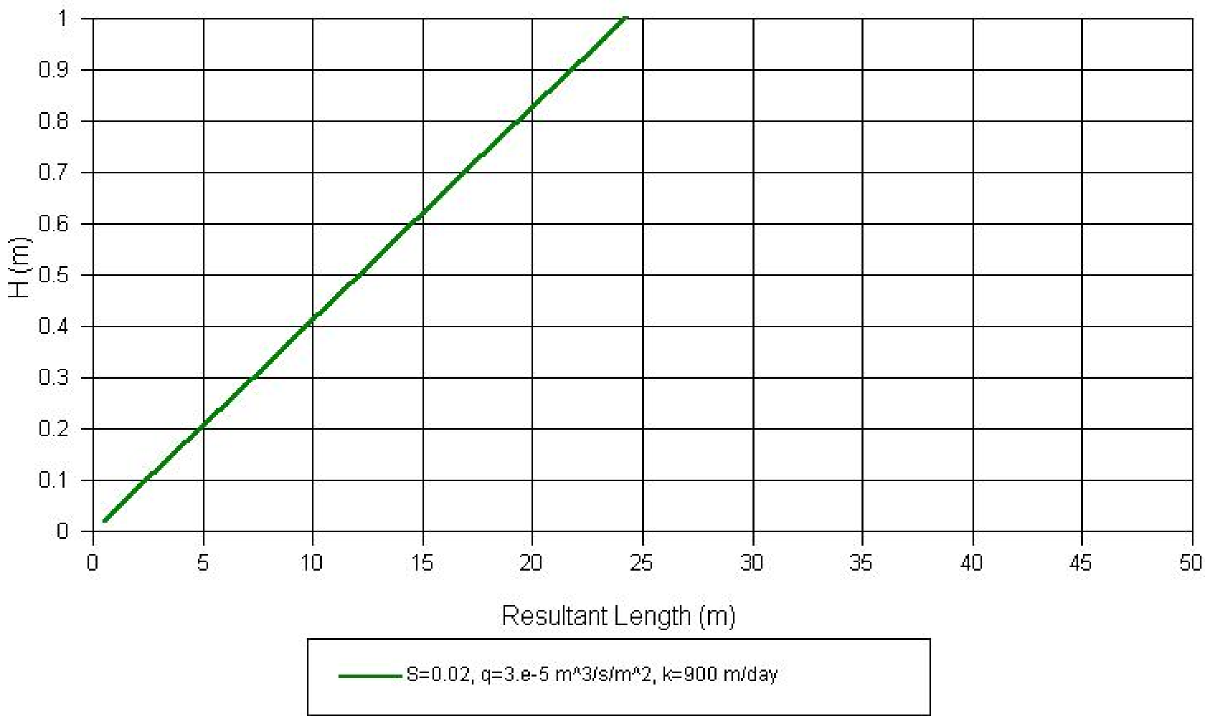


Figure 62. Minimum base thickness versus resultant length of drainage path.

Infiltration Rate

Figure 63 shows that the required base thickness is sensitive to the rate of infiltration, with the required thickness increasing as q_i increases, as would be expected. While there is large sensitivity to changes in q_i when the value is very small, the sensitivity becomes more linear after H reaches a more reasonable value (greater than 0.15 m).

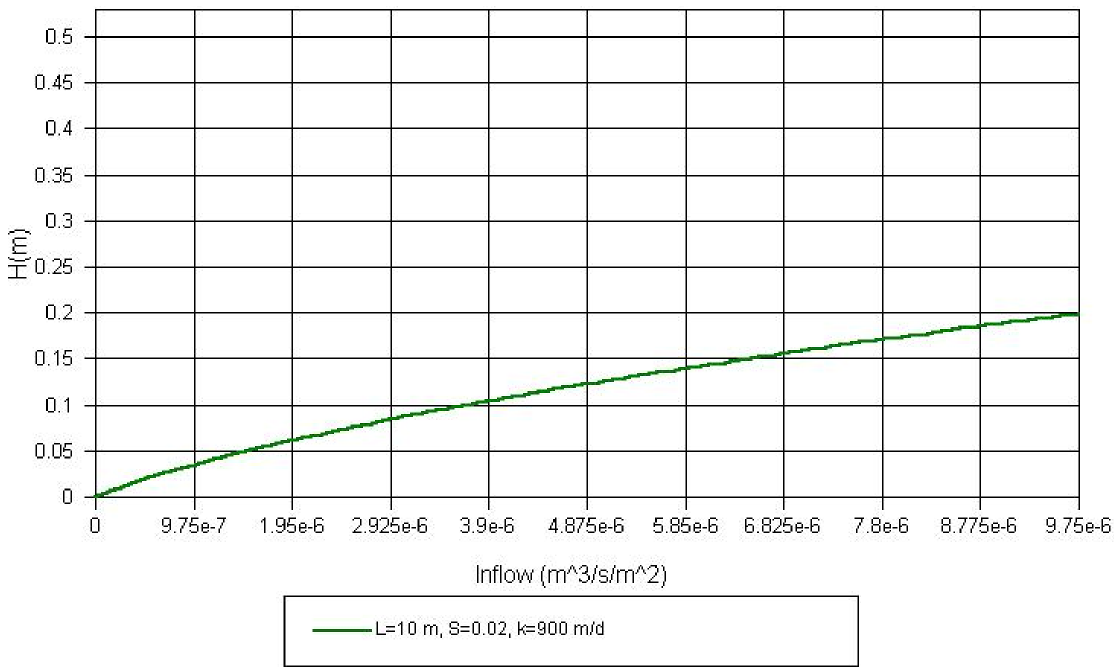


Figure 63. Minimum base thickness versus infiltration rate.

REFERENCES

1. Mallela, J., G.E. Larson, T. Wyatt, J.P. Hall, and W. Barker. *User's Guide for Drainage Requirements in Pavements – DRIP 2.0 Microcomputer Program*, FHWA Contract No. DTFH61-00-F-00199, July 2002.

APPENDIX TT.1 – STANDARDIZED NOMENCLATURE

ROADWAY GEOMETRY

Symbol	Item	English	SI
S	Longitudinal slope	ft/ft	m/m
S_X	Cross slope	ft/ft	m/m
S_R	Resultant slope	ft/ft	m/m
L_R	Resultant length of flow through base	ft	m
W	Width of permeable base	ft	m
A	Angle between roadway cross slope and resultant slope		

PAVEMENT INFILTRATION

q_i	Rate of pavement infiltration	$ft^3/d/ft^2$	$m^3/s/m^2$
C	Infiltration ratio		
R	Rainfall rate	in/hr	mm/hr
I_C	Crack infiltration rate	$ft^3/d/ft$	$m^3/s/m$
N_C	Number of longitudinal joints or cracks		
W_C	Length of contributing transverse joints or cracks	ft	m
C_S	Spacing of contributing transverse joints or cracks	ft	m
W	Width of permeable base	ft	m
k_p	Pavement permeability	ft/day	m/sec
N	Number of contributing traffic lanes		

PERMEABLE BASE DISCHARGE

q_d or Q_p	Permeable base discharge rate	$ft^3/d/ft$	$m^3/s/m$

OUTLET SPACING

Q	Pipe flow	ft^3/day	m^3/s
L	Longitudinal length of contributing roadway	ft	m
W	Width of contributing roadway	ft	m

SOILS

Symbol	Item	English	SI
C_u	Coefficient of Uniformity		
D_{10}	Effective size		mm
D_{XX}	Soil particle size		mm
γ_d	Dry unit weight of material	lb/ft^3	kN/m^3
	Unit weight of water	$62.4\ lb/ft^3$	$9.81\ kNm^3$
G_{SB}	Bulk specific gravity		
N or n	Porosity		
N_e or n_e	Effective porosity		
V_V	Volume of voids		
V_W	Volume of water		
V_T	Total volume		
WL	Water loss		
U	Percent drained		
S	Percent saturation		

DARCY'S LAW

Q	Flow capacity of base	cu ft/day	m^3/s
k	Coefficient of permeability	ft/day	m/d
i	Hydraulic gradient	ft/ft	m/m
A	Cross sectional area of flow	sq ft	m^2
H	Thickness of permeable base	ft	mm
V_S	Seepage velocity	ft/day	m/s
V	Discharge velocity	ft/day	m/s

TIME TO DRAIN

t	Time to drain	hr	hr
T	Time factor		
m	"m" factor		
S_1	Slope factor		

GEOTEXTILE

O_{95}	Opening size of geotextile in which 95% of the the openings are smaller		mm
O_{XX}	Opening size of geotextile		mm

PIPE FLOW

Symbol	Item	English	SI
Q	Pipe capacity	cu ft/day	m^3/s or l/s
D	Pipe diameter	in	mm
S	Slope	ft/ft	m/m
n	Manning's coefficient		
A	Flow area	sq ft	m^2
P	Wetted perimeter	ft	m
R	Hydraulic radius	ft	m
K	Conveyance		
V	Velocity	ft/sec	m/s