Asphalt Institute

SW-1

Asphalt Pavement
Thickness Design Software

for Highways, Airports, Heavy Wheel Loads and Other Applications

User's Guide

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SW-1 User's Guide

SW-1 was developed by the Asphalt Institute and IIT Corporation.

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Disclaimer

All reasonable care has been taken in the preparation of SW-1 and it is believed to be accurate; however, the Asphalt Institute accepts no responsibility for the consequences of any inaccuracies that it may contain, or its suitability or utility for use in any specific set of circumstances. **Always use sound engineering judgment.**

The example problems in SW-1 and this User's Guide are fictitious and for demonstration purposes only. No association with policies or practices of actual public agencies or organizations is intended or should be inferred.

Contents

Chapter 1

About SW-1

Welcome to SW-1, Thickness Design Software for Asphalt Pavements from the Asphalt Institute! SW-1 is a powerful tool for use in design and analysis of asphalt pavement structures for a wide variety of applications.

SW-1 provides a computerized methodology for thickness design of asphalt pavements for a wide variety of pavement uses. With this single program, a user can design pavements for the following vehicle types and uses:

- **Commercial Airports**
- **General Aviation Airports**
- **Highways**
- **Roads**
- **Streets**
- **Parking Lots**
- **Port and Marine Facilities**
- **Industrial and Heavy Wheel Load Applications**

SW-1 also provides the advanced user the capability to conduct straightforward, yet powerful **structural analysis of special pavement structures** using DAMA.

SW-1 is based on the respected design procedures of the Asphalt Institute as detailed in several Asphalt Institute manual series (MS), information series (IS), and research report (RR) documents. These methods are based on mechanistic-empirical principles and have been developed and refined over a period of 30 years by the Asphalt Institute.

While SW-1 is a stand-alone computer program, the user is encouraged to become familiar with the individual design procedures that are used in the program. The Asphalt Institute methods differ in some ways to other common pavement design methods and it is best that the user is fully aware of the background, assumptions, and conditions that apply to each thickness design procedure. Table 1 lists the pertinent Asphalt Institute documents that form the basis of the methods included in the SW-1 thickness design software.

Table 1—Index to Asphalt Institute Publications

Publication	Pavement Use
IS-91	Asphalt Pavements for Parking Lots, Service Stations, and Driveways
IS-154	Thickness Design—Asphalt Pavements for General Aviation Airports
IS-181	Asphalt Pavement Thickness Design—A Simplified and Abridged Version of the 1981 Edition of the Asphalt Institute's Thickness Design Manual (MS-1)
MS-1	Thickness Design—Asphalt Pavements for Highways and Streets
MS-11	Thickness Design—Asphalt Pavements for Air Carrier Airports
MS-17	Asphalt Overlays for Highway and Street Rehabilitation
MS-23	Thickness Design—Asphalt Pavements for Heavy Wheel Loads
RR-82-2	Research and Development of the Asphalt Institute's Thickness Design Manual (MS-1) Ninth Edition
The hyperlinks in this table will direct you to the appropriate page on the Asphalt Institute website where you can find details, pricing, and ordering instructions.	

Background

SW-1 is a new Microsoft Windows-based computerized method for pavement thickness design that builds upon four familiar Asphalt Institute DOS computer programs for pavement design. The four DOS-base programs were DAMA (CP-1), HWLOAD (CP-2), AIRPORT (CP-3), and HWY (CP-4).

The developers of SW-1 embedded the original computational algorithms from DAMA, HWLOAD, AIRPORT, and HWY into SW-1 and developed a new Windows user-interface to collect input data, report output, and manage data files.

One of the benefits of this approach is a versatile and powerful new user-interface that allows the user to solve a wide variety of problems from the same program. The effect of this design approach is that SW-1 has the same look and feel of Windows-based programs while maintaining the computational integrity of the original DOS-based programs, all within a single, straightforward, package.

What's new in SW-1?

SW-1 offers users new functionality and versatility in handling a wide variety of pavement designs. The Asphalt Institute was motivated to develop SW-1 due to the age of the older DOS-based programs and the many benefits of using a familiar operation system such as Windows. As such, SW-1 users reap the benefits of having access to the venerable Asphalt Institute thickness design methods all within the comfortable and familiar user-interface that operates on the latest computers. Specific benefits are:

- SW-1 is designed to run on common Microsoft Windows operating systems including Windows XP.
- New Windows-based User-Interface dramatically eases the use program use.
- Improved data file handling and management capability.
- Extensive HELP file and companion User's Guide addresses common technical and procedural questions in pavement design problems.
- Retains the computational integrity of the legacy programs DAMA, HWY, AIRPORT, and HWLOAD.

Acknowledgements

SW-1 was developed by the Asphalt Institute and Intelligent Information Technologies of Indianapolis, Indiana.

HWLOAD, AIRPORT and HWY were developed at the Asphalt Institute by Dr. R. W. May.

DAMA was developed for the Asphalt Institute by Dr. M. W. Witczak and D. Hwang.

Chapter 2

Installing SW-1

SW-1 is Distributed as a Trial Version

SW-1 is distributed as a trial version. The trial version operates for a period of 30 days to allow users the opportunity to view example problems, get a better understanding of the capabilities in SW-1, and make a decision whether to purchase a software license. When a user purchases and activates a license for SW-1, the full capability of SW-1 is unlocked. This process is called license activation.

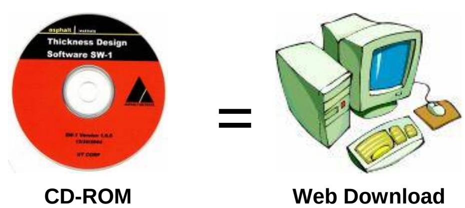


Figure 1--CD-ROM and Web Download Versions of SW-1 are the same

Interested users can obtain a copy of SW-1 from either a CD-ROM or by downloading a copy of the program from the Asphalt Institute website. Regardless of how the program is distributed, a user can install SW-1 from the following file:

SW1-Install.exe

Before installing SW-1, take a moment to review the system requirements listed in this chapter.

System Requirements

SW-1 is designed to run on a variety of computer platforms and Windows operating systems. Your computer must meet the following minimum requirements:

- Computer: IBM or compatible Pentium 200 or higher
- Operating System:
    a. Windows 98, 98SE
    b. Windows ME

c. Windows NT

d. Windows 2000 Professional

e. Windows XP Professional or Windows XP Home Edition

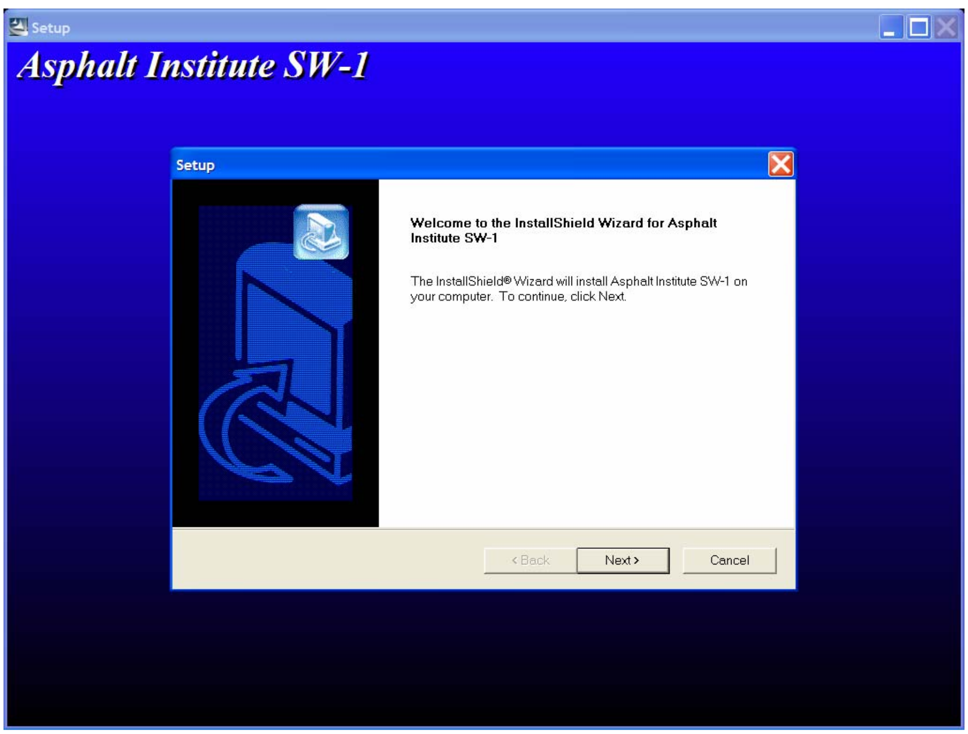
- Memory: 32 MB RAM (128 MB RAM recommended)
- Hard Disk Space: 100 MB of available hard disk space
- Monitor: SVGA (800x600) with 256 colors
- CD-ROM Drive: Double speed or higher
- Printer: Any printer supported by Windows 98/ME/NT/2000/XP

Installation

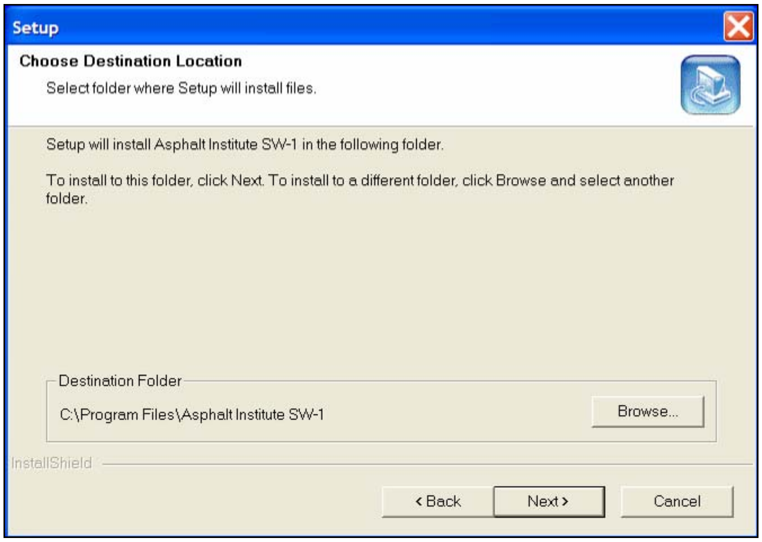
Note: If you have a previous version of SW-1 installed, you must uninstall it before you can install this version of SW-1.

To install SW-1

1. Locate the file **SW1-Install.exe** on the CD-ROM or in the directory where it was downloaded. Double-click the file to begin the installation process.



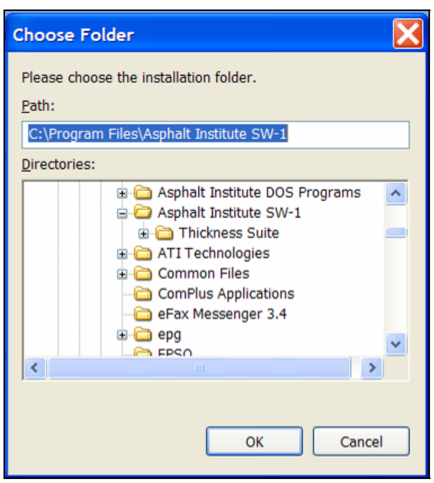
2. On the InstallShield Wizard for SW-1 Thickness Design Software Welcome screen, click **Next**.



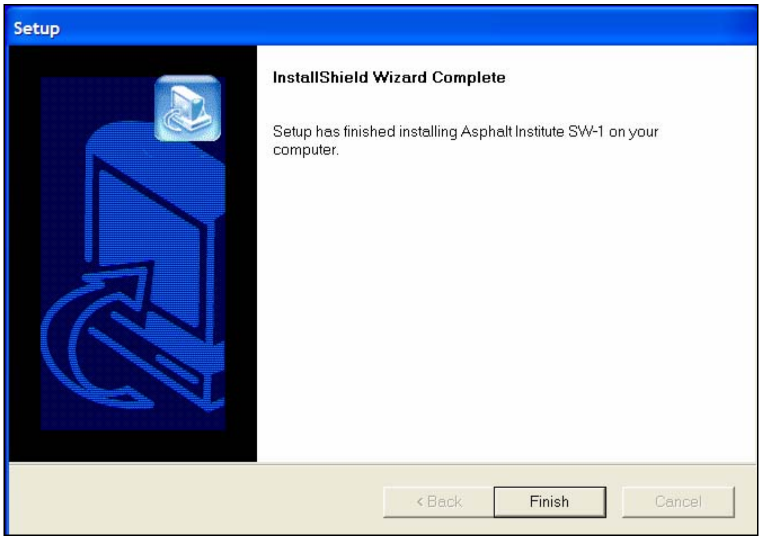
3. The next window allows you to choose where the SW-1 files will be installed on your computer. In the Choose Destination Location window, you can select the default location or use the browse function to select a custom destination location.

   If you want to accept the default location, click **Next** to continue installation.

   If you want to install SW-1 in a different directory, click **Browse**. You will be directed to a separate Choose Folder window as shown below. Once you have selected your installation directory, click **OK**. On the Choose Destination Location window, click **Next** to continue installation.



4. Once the installation process is complete, the InstallShield Wizard Complete window will appear. Click **Finish** to close complete the Setup process and close the window. Remove the CD from the CD-ROM drive and store in a safe place.



If the opening screen does not appear

Sometimes, a computer's CD-ROM drive does not automatically start a CD.

To start the installation from the SW-1 CD

1. On your desktop, double-click **My Computer**.
2. In the My Computer dialog box, double-click the icon for your CD-ROM drive.
3. From the list of files, double-click **SW1-Install.exe**.

Trial Version Evaluation

Once SW-1 is installed, the user will have access to a set of example problems which showcase the capabilities of the software package. The evaluation period can last up to a period of 30 calendar days from the date of installation.

At any time during the 30 day evaluation period, the user can activate the program by starting SW-1 and following the activation prompts or by selecting **Help > Activate SW-1.**

After 30 days, the evaluation period will have ended and the user will no longer be able to run the program in evaluation mode. Upon starting SW-1, the user will then be prompted to either activate the software or to close the program.

License Activation

In order to unlock the full capability of SW-1, you must first purchase a license and activation key from the Asphalt Institute. By entering the activation key code into SW-1, the trial version will be converted to a fully operational version of the software.

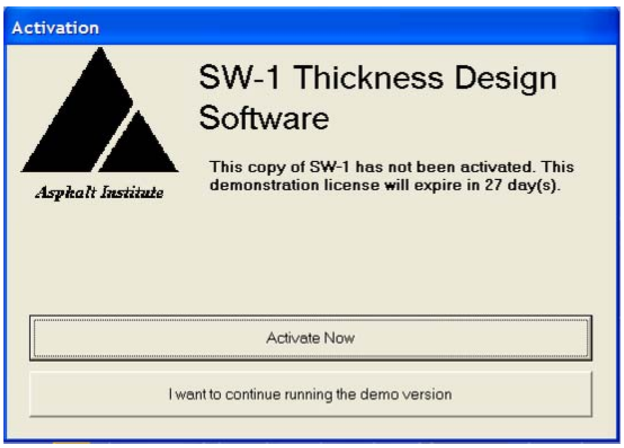
Note—The Asphalt Institute currently sells SW-1 licenses to individual users for use on a single computer. Site licenses for multiple users are not currently offered, but may be offered in the future.

The licensing process binds SW-1 to one computer using a system of encrypted codes. The codes used during the activation process are unique to the computer system on which SW-1 is being installed. If you want to install SW-1 on more than one computer, you will need to purchase an additional license.

There are six steps in licensing the SW-1 software.

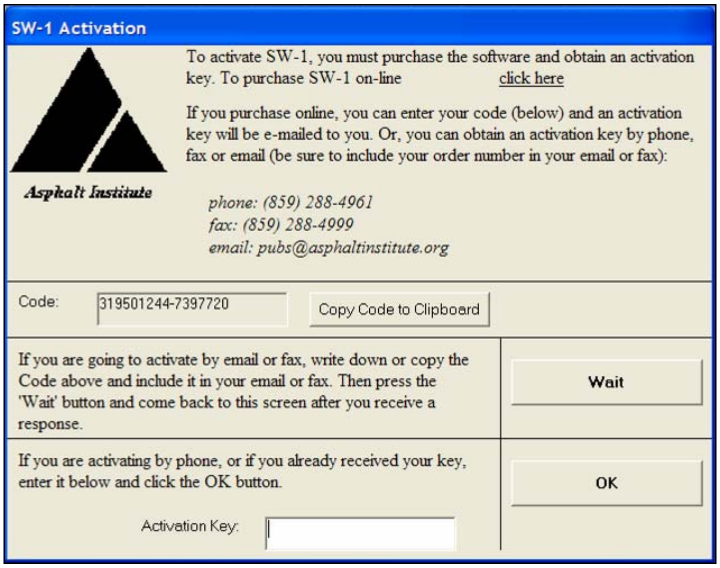
To obtain a license and activate SW-1

1. When you start SW-1 during the trial period, you will see the Activation dialog box during start up. Click **Activate Now** to initiate the activation process.



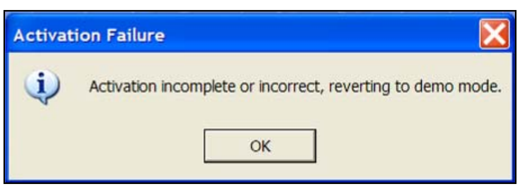
As an alternative, you can select **Help > Activate SW-1** from the main menu within the SW-1 program

2. On the following SW-1 Activation screen, you will be prompted to contact the Asphalt Institute to obtain an activation key. If you have not paid for the software, you will first be asked to purchase the software. If you have already paid for the software and are just obtaining a license, you can skip to the next step.



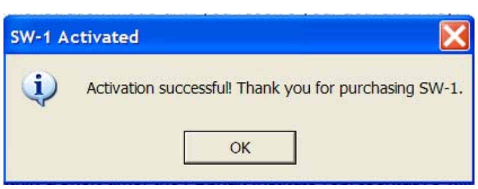
Note—If you contact the Asphalt Institute by telephone, please be aware that our office is in Lexington, Kentucky, in the U.S. Eastern Time zone (GMT -05:00 hours). Our office is staffed during normal business hours, 8:00 AM to 5:00 PM, Monday through Friday. You can email or fax your User Code to the Asphalt Institute at any time. Our representatives will respond as soon as possible once we receive your payment and User Code.

3. Submit the Code that appears on the activation screen to the Asphalt Institute representative. This code can be submitted by email, fax, or by phone. Once you have submitted the code, you can click **Wait** to operate SW-1 in the demonstration mode until you receive your activation key. The following message will appear until you correctly enter the activation key.



4. Within a short time, the Asphalt Institute representative will provide you a unique activation key that will unlock SW-1 and serve as your software license.

5. Enter the activation key in the box on the SW-1 Activation screen and click **OK** on the Activation screen to complete the license activation process. The following message confirms that the activation process has been successfully completed.



If you need to transfer SW-1 to another computer

During the license activation process, SW-1 will be bound to your computer using a series of encrypted codes. Your software license allows you to install SW-1 on a single computer. If you need to have SW-1 installed on more than one computer simultaneously, you must purchase and activate a second license for the second computer.

You may have a need to transfer SW-1 from one computer to another. This occurs most commonly when a user upgrades his or her old computer to a newer model.

To transfer SW-1 from one computer to another

Note—You must install SW-1 on the new computer prior to attempting to transfer a license. Follow the installation instructions provided earlier in this chapter.

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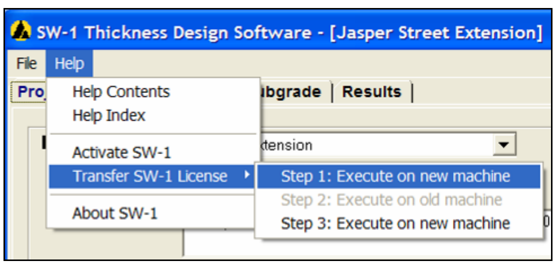
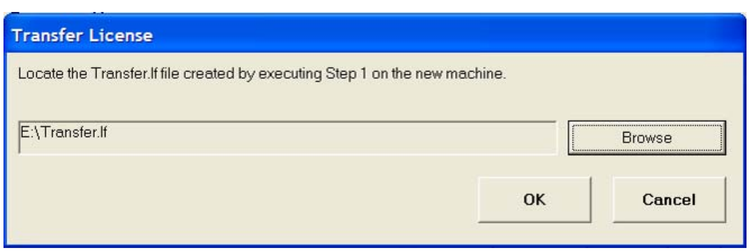
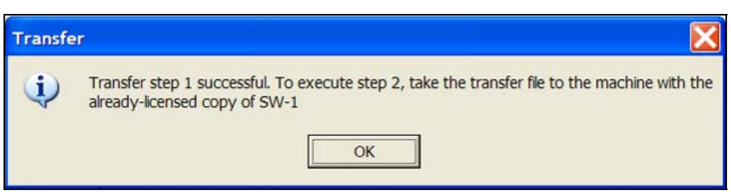
1. On the new computer, open SW-1 and select **Help > Transfer SW-1 License > Step 1: Execute on new machine**



This step creates a file called **Transfer.lf.** Click **Browse** and identify the directory where you would like to create **Transfer.lf**.

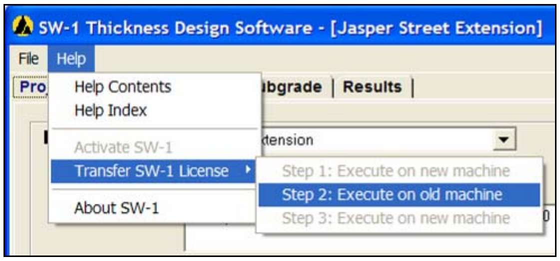


After you identify the path to the desired location to create **Transfer.lf** file, click **OK.** SW-1 will then create the **Transfer.lf** file in the specified location. A dialog box will appear instructing you to copy the **Transfer.lf** file to the old machine.

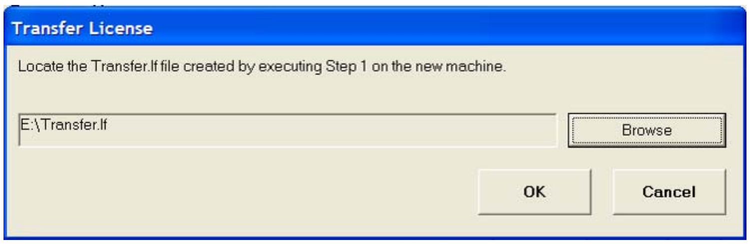


Copy the **Transfer.lf** file from the new computer to the old computer.

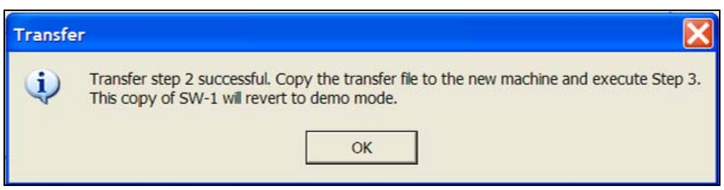
2. On the old computer, open SW-1 and select **Help > Transfer SW-1 License > Step 2: Execute on old machine**



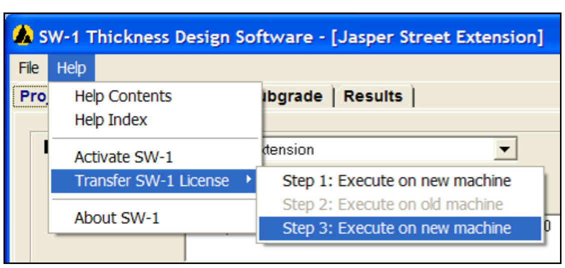
Locate the **Transfer.lf** file you just copied to the old computer. To locate the file, click **Browse** and locate, on the old computer, the directory to which **Transfer.lf** was copied. Once you have identified the path for **Transfer.lf**, click **OK**.



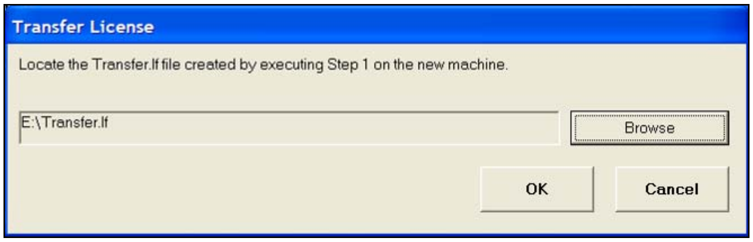
At this point you have successfully completed step 2 in the license transfer process. The copy of SW-1 on the old machine will no longer be fully licensed and will revert to the trial version of the software. Click **OK** to continue to Step 3.



3. The last step of the transfer process will activate the full version of SW-1 on the new machine. This step requires that the **Transfer.lf** file created in Step 1 and used in Step 2 be copied back to the new machine. On the new machine, initiate Step 3 by selecting **Help > Transfer SW-1 License > Step 3: Execute on new machine**.



In the Transfer License dialog box, click **Browse** to locate the **Transfer.lf** file.



Once the **Transfer.lf** file has been located, click **OK** to transfer the license to the new computer. If the transfer is successful, a dialog box will appear instructing you that the license transfer to the new machine has been successful. Click **OK**.

If you need to uninstall SW-1

If you need to remove SW-1 from your computer use the **Add/Remove Programs** feature in your version of Windows.

Note: The following information applies specifically to Windows XP Professional. Please refer to the specific documentation provided with your version of Windows for specific instructions.

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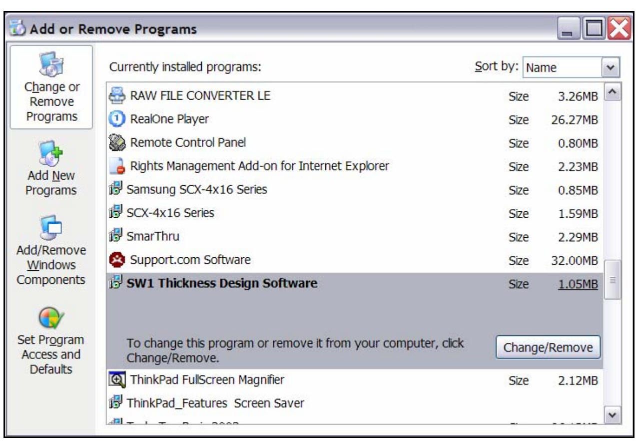
1. On the Windows taskbar, click **Start > Control Panel**

2. Double-click **Add or Remove Programs**



3. From the Add or Remove Programs window, select SW-1 Thickness Design Software and click **Change/Remove**.

4. Click **Yes** to confirm uninstall.

5. When uninstall is complete, click **OK**.

If you need assistance

The first place to look for help is in this User's Guide or the Help File embedded within SW-1.

In addition, be sure to check the SW-1 Support section of our website at

http://www.asphaltinstitute.org/thicknessdesignsw/

You will find a technical library, FAQs, and support contacts including a technical support contact form.

You can send us an email at sw1@asphaltinstitute.org

Our World Wide Web address is http://www.asphaltinstitute.org

Chapter 3

Basic Operations

SW-1 was designed for pavement design professionals who may have the need to design pavements for a wide variety of uses including airports, roadways, and parking lots. Rather than turn to individual specialty programs for each type of pavement, the SW-1 integrates its pavement thickness design tools in a single program for exceptional versatility.

The key to this versatility lies in the Project Definition screen, SW-1's opening screen. On the Project Definition screen you can define the project to be designed by selecting the Pavement Use (i.e. general aviation airport or highways, roadways, and streets) and the Project Type (i.e. new pavement or overlay). Once you define the project, SW-1 creates the proper tabs to step you through the specific design problem-at-hand.

This chapter covers basic operations that are common to all pavement designs completed in SW-1. This includes file operations, managing data files, screen layout, managing project records, defining units, project definition, view results, and printing from SW-1.

File Operations

Underlying the user-interface, SW-1 is powered by a Microsoft Access database. SW-1 files are saved in Microsoft Access format using a ***.MDB** extension. SW-1 uses common Windows file operations to open, save, rename, and delete files.

There are two levels of hierarchy in managing files and projects in SW-1: data files and project records. At the higher level in the hierarchy, you can create and manage data files using the **File > New** or **File > Open** operations from the SW-1 main menu. Within each data file, you can establish and manage numerous project records. In the example in Figure 2, data file **SW-1 Example Problems.mdb** includes nine project records.

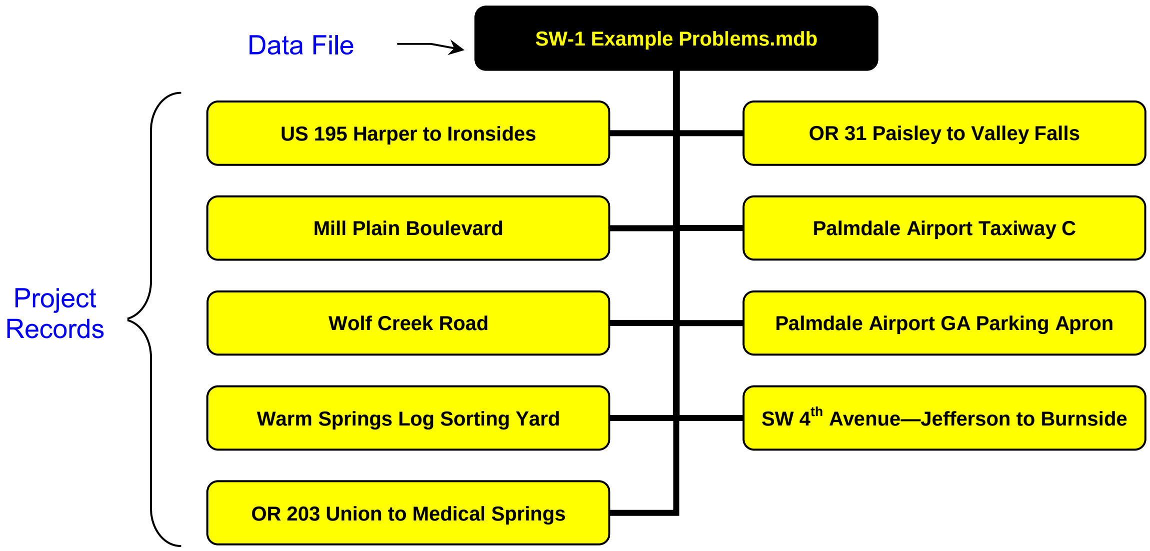
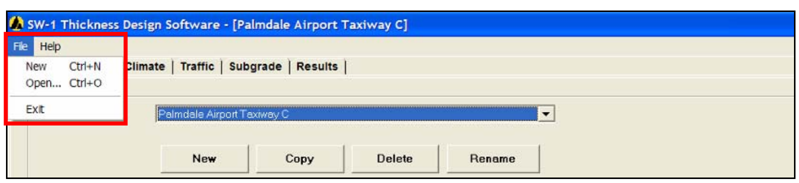


Figure 2—SW-1 relationship between data files and project records

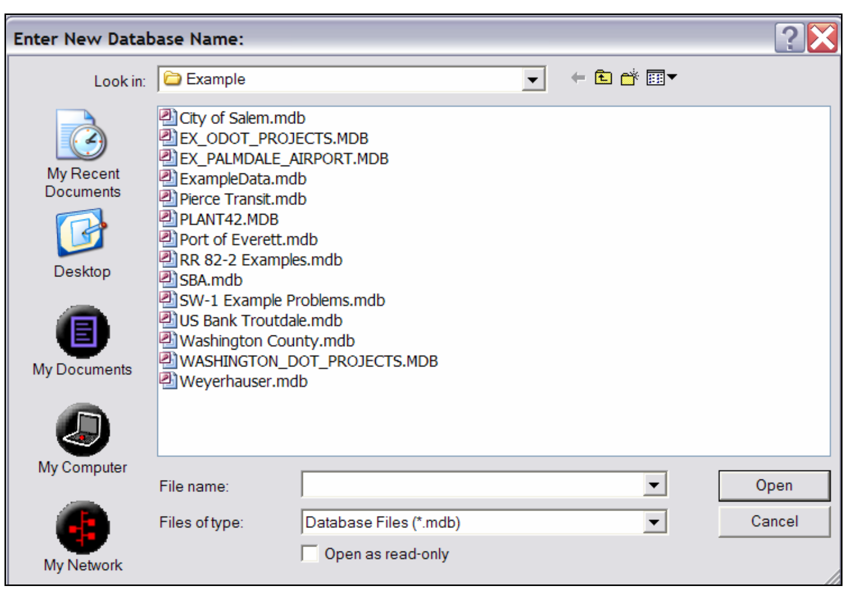
Managing Data Files

To create a new data file

1. On the SW-1 menu, select **File > New**



2. In the Enter New Database Name window, go to **File Name** and enter the name of the data file you wish to create.



3. Click **Open**.

To open an existing data file

1. On the SW-1 menu, select **File > Open**

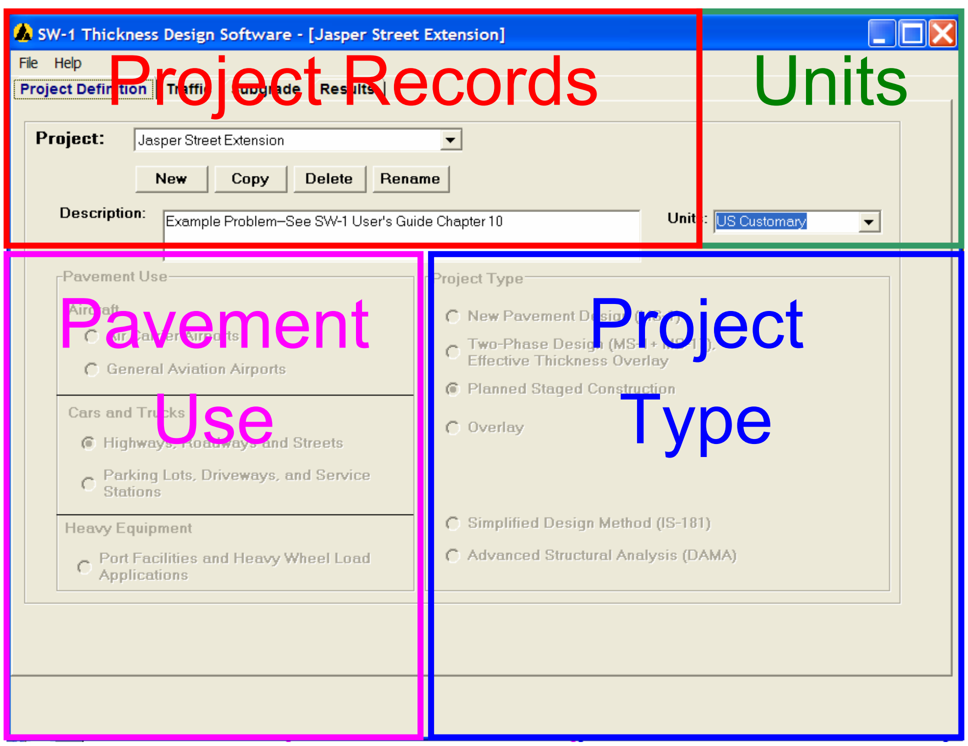
2. In the Enter New Database Name window, select the data file you wish to open

3. Click **Open**.

Screen Layout

The SW-1 program incorporates a user-friendly interface. The opening screen that you come to is called the Project Definition screen. On this screen you can manage project records, select units of measure, and define the pavement use and project type for your specific application.

The Pavement Use and Project Type regions of the Project Definition screen appear grayed out, indicating the selected pavement use and project type for the problem. Pavement Use and Project Type are selected during the process of creating a new record in the Project Record region of the screen.

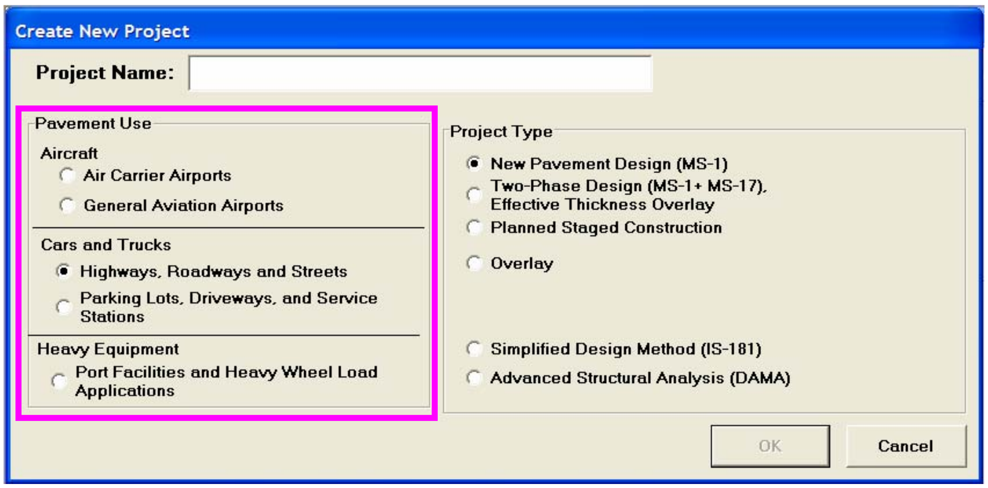


Creating New Project Records

One of the primary advantages of the SW-1 program is its ability to solve a wide range of pavement design problems. The key to this versatility lies in the ability to "define" a project as the project record is created. Project Definition is accomplished by selecting the appropriate radial buttons for Pavement Use and Project Type on the Create New Project screen.

Pavement Use is determined primarily by the vehicle type that will use the pavement facility. There are five distinct pavement uses defined in SW-1. For aircraft, SW-1 distinguishes between air carrier airports and general aviation airports. For cars and trucks, highways, roadways, and streets are designed with methods that are different that those for parking lots, driveways, and service station lots. Lastly, SW-1 has the capability to design pavements for heavy equipment that operate at port facilities, log-sorting yards, and other industrial applications.

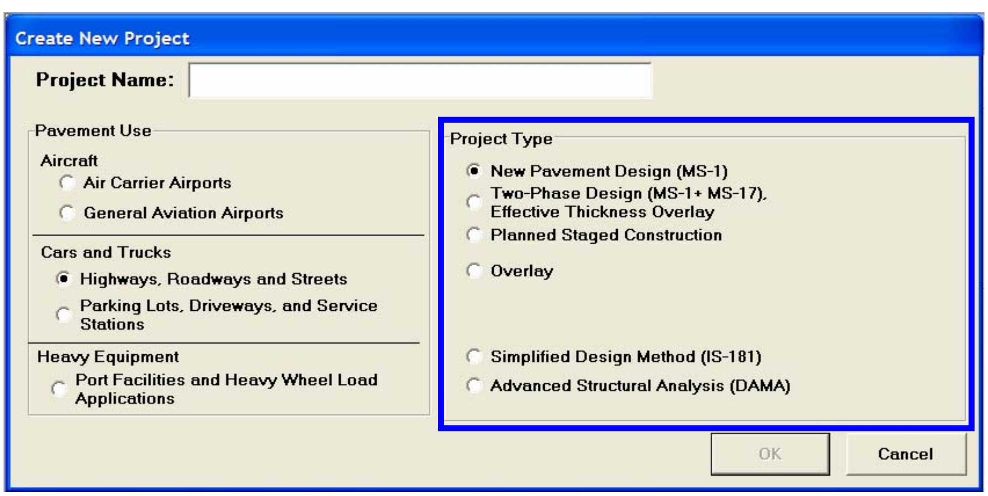
To define Pavement Use select the appropriate radial button



Note: You must select both Pavement Use and Project Type in order to properly set up a project and establish the proper screens to complete the pavement design.

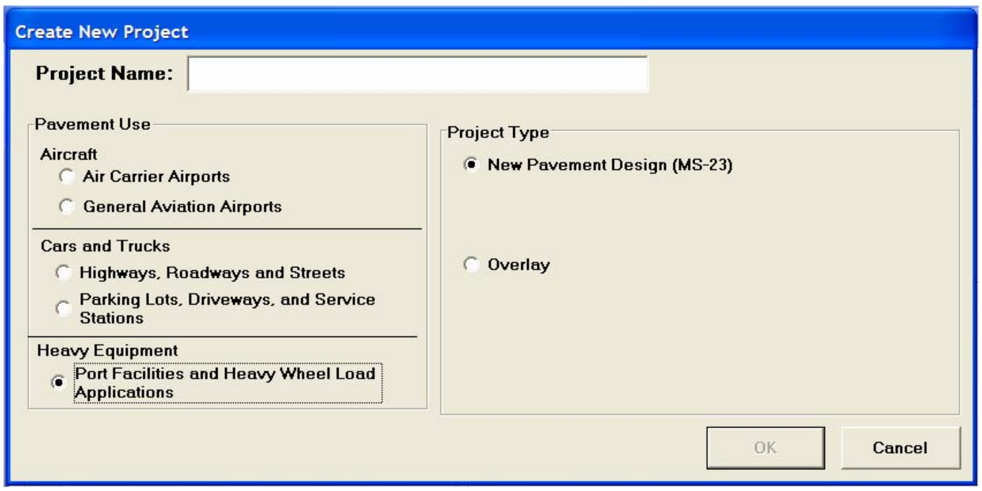
To define Project Type select the appropriate radial button

The Project Type area of the screen would look like this when Highways, Roadways and Streets is selected as the Pavement Use



Note: In the Asphalt Institute methodology, only certain combinations of Pavement Use and Project Type are valid. Upon selecting a Pavement Use on the left half of the screen, only valid Project Types for the selected Pavement Use will be visible on the right half of the Project Definition screen.

When Port Facilities and Industrial Applications is selected as the Pavement Use, the Project Type area of the screen would offer only two options, New Pavement Design (MS-23) and Overlay.



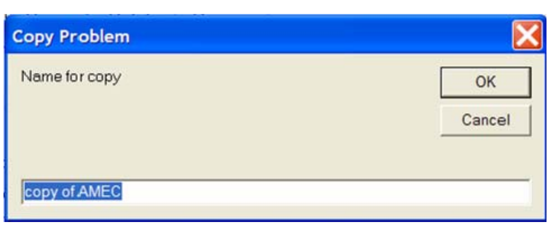
Managing Project Records

Project records can be managed using the **Copy**, **Delete**, and **Rename** buttons in the Project Records area of the Project Definition screen.

To copy a project record

1. On the SW-1 Project Definition screen, click **Copy**

2. In the Copy Project window, enter a name for the copied project record in the space provided, then click **OK**.



To delete a project record

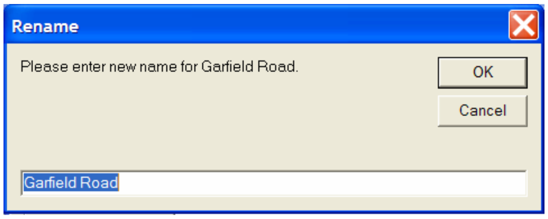
1. On the SW-1 Project Definition screen, click **Delete**

2. In the Confirm Delete window, click **OK**.

To rename a project record

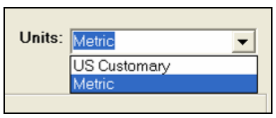
1. On the SW-1 Project Definition screen, click **Rename**

2. In the Rename Project window, enter the new name for the project record in the space provided, then click **OK**.

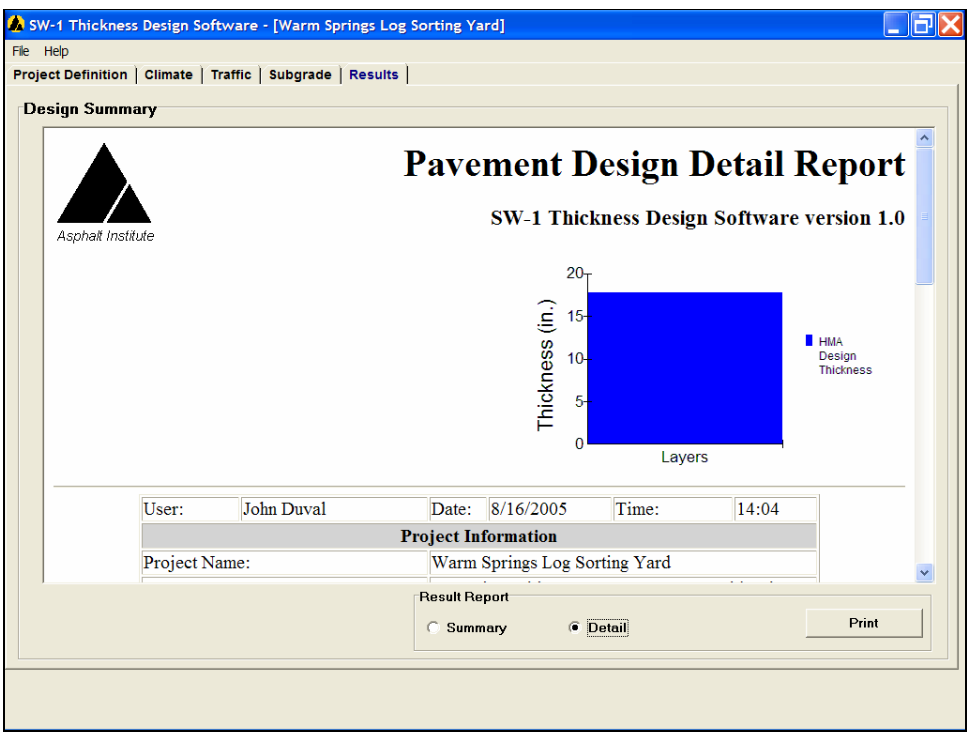


Defining Units

SW-1 allows you to select either US Customary or Metric units from the **Units** dropdown list on the Project Definition screen. This selection applies to all aspects of the project including inputs for climate, traffic, subgrade as well as results.



Viewing Results



For any project in SW-1, results can be viewed by either proceeding through the pavement design program using the **Next** button. Alternatively, for existing project records, results can be viewed simply by selecting the **Results** tab. Upon selecting the **Results** tab, SW-1 runs design calculations and presents the results in a text report.

Report Format

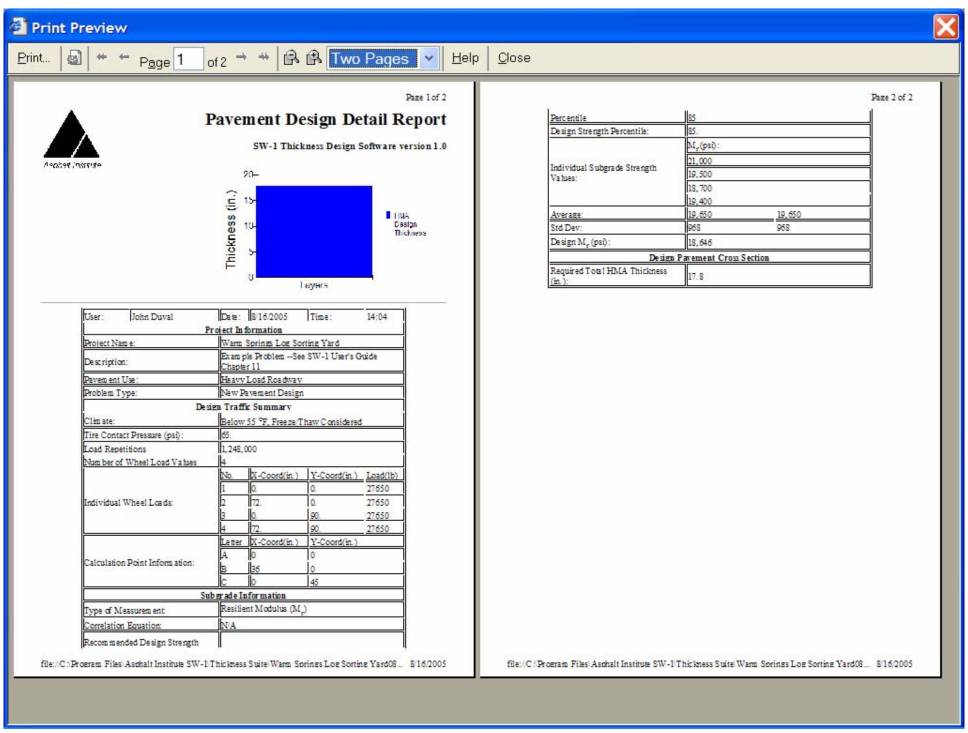
In most cases, the SW-1 program reports results in two formats—a summary or detailed version of the report. A summary report typically shows basic project information and the design results. The detailed report lists project information, subgrade, climate, and traffic inputs along with the design results. You can scroll down to view the reported results and preview the entire report. The summary report format rarely exceeds one-page in length, while some detailed reports can be several pages long. For most reports, a simple graphic at the top of the page shows relative layer thicknesses on a graphic scale.

Printing

To Print a Pavement Design Report

1. On the Results tab, choose **Summary** or **Detailed** report format

2. Select the **Print** button.



Note: Reports are automatically displayed in Print Preview mode to allow you to view the report as it will be printed. Various zoom levels can be selected to allow viewing the report at several levels of detail.

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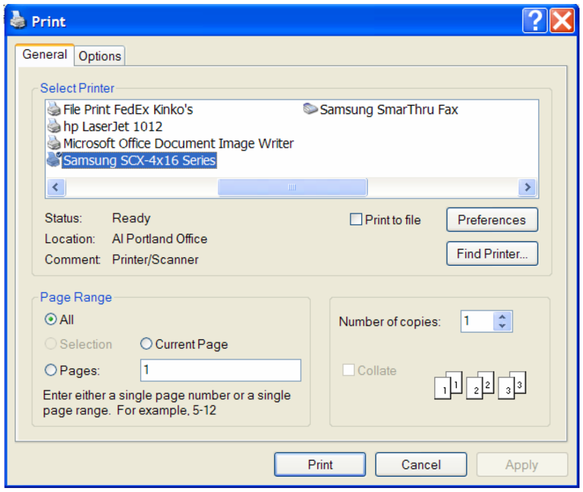
3. From the Print Preview screen, select **Print**.

4. In the Windows Print window, select the desired printer and select **Print**.



Chapter 4

Climate

Climatic conditions affect the behavior of pavement materials. For hot-mix asphalt, the stiffness of the layer depends on the temperature of the mat. Consequently, temperature affects the response of the HMA layer to loading and affects the critical strains that result.

For unbound aggregate and subgrade soils, we are concerned primarily with freezing and thawing conditions that will affect the stiffness of these materials.

SW-1 accounts for variations in climate in two ways. First, for most analyses, SW-1 uses an average temperature to characterize the climate conditions that apply to the project at hand. SW-1 does this by asking the user to specify the mean annual air temperature (MAAT) for the project location. Once the MAAT is selected by the user, SW-1 applies the appropriate corrections to account for temperature effects such as freeze-thaw. In the advanced structural analysis using DAMA, SW-1 offers the ability to input monthly temperature variations. More details follow below.

Mean Annual Air Temperature

The Asphalt Institute design methods make allowance for the influence of climate, or more specifically temperature, on pavement performance. The input needed in the analysis is the mean annual air temperature (MAAT) for the design site.

MAAT is a simplified way of describing climate conditions that have common cyclic temperature variations. Although we use MAAT as an input in the pavement design process, it is important to recognize the significance of MAAT and the inherent variability that it assumes.

An example of three different MAAT levels is shown in Figure 3. This figure shows the monthly temperature variations for the three MAAT levels used in the development of MS-1, namely 45ºF, 60ºF, and 75ºF which correspond to New York, South Carolina, and Arizona, respectively. All three locations have significant variation in air temperature over the course of a year. For example, in New York, MAAT45, the monthly air temperature averages dip below freezing during the months of January through April. During this period, all layers will experience increased stiffness due to the cold. In April, as the temperature climbs, some thawing is to be expected, which will likely weaken the subgrade soils. After thaw weakening, temperatures warm up during the spring and summer months and HMA layers will experience lower stiffness as pavement temperatures climb. In the fall,

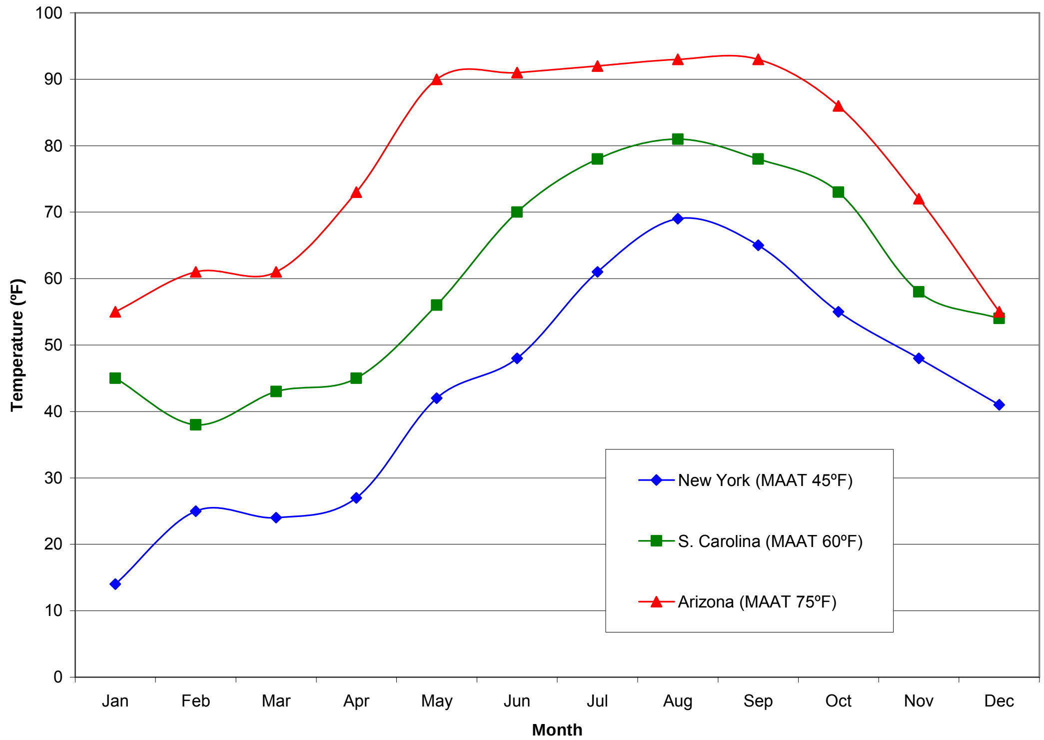


Figure 3—Variation in Mean Monthly Air Temperatures for Selected MAAT

as the temperatures cool off, HMA stiffness will begin to increase and the cycle repeats.

Freezing and Thawing

One of the primary advantages of analyzing variations in temperature of pavement structures is to allow for the freezing and thawing effects of subgrade soils and unbound base aggregates. Under freezing conditions, the stiffness of these underlying foundation materials increases dramatically. During the spring thaw, these same materials may experience a major reduction in stiffness due to the presence of the melting water.

These factors are considered in the selection of a representative MAAT for the pavement. For highway, street and road design, three sets of environmental conditions were selected to represent the range of conditions to which this procedure applies:

Table 2—MAAT Levels and Frost Effects

MAAT	Frost Effects
45 ºF	Yes
60 ºF	Possible
75 ºF	No

Another way to describe these three MAAT levels is that for MAAT45, freeze-thaw will occur during the cycle. At MAAT60, some freeze-thaw is possible with warm summer temperatures. Freeze-thaw is not considered at MAAT75 and hot summer temperatures will result in low HMA stiffness.

Note: Typically the 30-year mean is recommended for use in calculating a mean average annual air temperature. Air temperature information can be obtained from the National Weather Service station nearest to the site. For more information see the following website: www.nws.noaa.gov.

Note: While MAAT is used for most airport, highway, and heavy wheel load analyses, users wanting to perform a more detailed analysis can perform an advanced analysis using DAMA. DAMA allows the user to analyze the influence of monthly variations in temperature the pavement structure. For more information see Advanced Structural Analysis on page 85

SW-1 and MAAT Levels

The Asphalt Institute pavement design methods have evolved and been refined over the years with respect to MAAT levels. As described above, there are three MAAT levels in the highway design method detailed in MS-1. There are eight separate levels in the air carrier airport design method and only two levels in the heavy wheel load method. These differences reflect the evolution of the Asphalt Institute methods over the years. SW-1 maintains the legacy of the Asphalt Institute methods and uses the MAAT levels that correspond to the respective publication and "manual" design methods shown in Table 1 on page 8.

Chapter 5

Subgrade

On the subgrade screen, the user is asked to supply subgrade stiffness values as inputs to the pavement section design calculation. SW-1 uses the resilient modulus to characterize subgrade stiffness, but can correlate from CBR or R-values is the user has this type of information.

The user is asked to select the type of strength measure, input the stiffness values, and select a design subgrade value in order to calculate the Design Subgrade Resilient Modulus.

Types of Strength Measure

The basis for subgrade strength measurement in this program is the subgrade resilient modulus, which can be determined from a laboratory test in accordance with AASHTO Method T 307.

In order to facilitate the use of other widely used tests, correlations have been established with the California Bearing Ratio (CBR) and the Resistance (R) value. Procedures for performing CBR and R-value tests are detailed in MS-I0 and ASTM/ AASHTO test methods:

In SW-1 the default relationship used to correlate resilient modulus from a CBR test values is as follows, but may be changed by the user:

M_r (psi) = 1500 CBR

Similarly, the default relationship used by SW-1 to correlate resilient modulus from an R-value test is as follows:

M_r (psi) = 1155 + 555 (R-value)

CBR and R-value correlations are considered applicable to fine-grained soils classified as CL, CH, ML, SC, SM, and SP (Unified Soil Classification) or for materials that are estimated to have a resilient modulus of 30,000 psi. or less. These correlations are *not* applicable to granular materials, such as base aggregate, which may require direct laboratory testing to obtain resilient modulus values.

Selection of Design Values

The Design Subgrade Resilient Modulus is the value of the subgrade resilient modulus (M_R) used for designing the pavement structure. It is a percentile value of the subgrade resilient modulus test data distribution.

One or more individual data points may be used to characterize subgrade stiffness. If a single value is used, SW-1 selects it as the design value. If a set of two or more test values, the default subgrade design value is as shown in Table 3, but the user is allowed to override the default value by selecting a subgrade design value from the drop-down list.

This procedure allows the user to look at the statistical significance of the data set before selecting the design value. It requires more conservatism as the traffic volume increases and allows for less conservatism on low volume designs.

Table 3—Recommended Subgrade Design Values

Pavement Use	Traffic Level	Design Subgrade Value, Percent
Highways, Roadways, and Streets	10^4 ESALs or less	60
	Between 10^4 and 10^6 ESALs	75
	10^6 ESALs or more	87.5
Airports	All	85
Port Facilities and Heavy Wheel Loads	All	85

However, for a large sample size, which typically results from a nondestructive testing program, a more direct statistical approach can be applied. If the number of sample data points is 30 or more, a normal distribution can be assumed for computing M_R using the following relationship:

Design M_r = x - Z * S

Where:

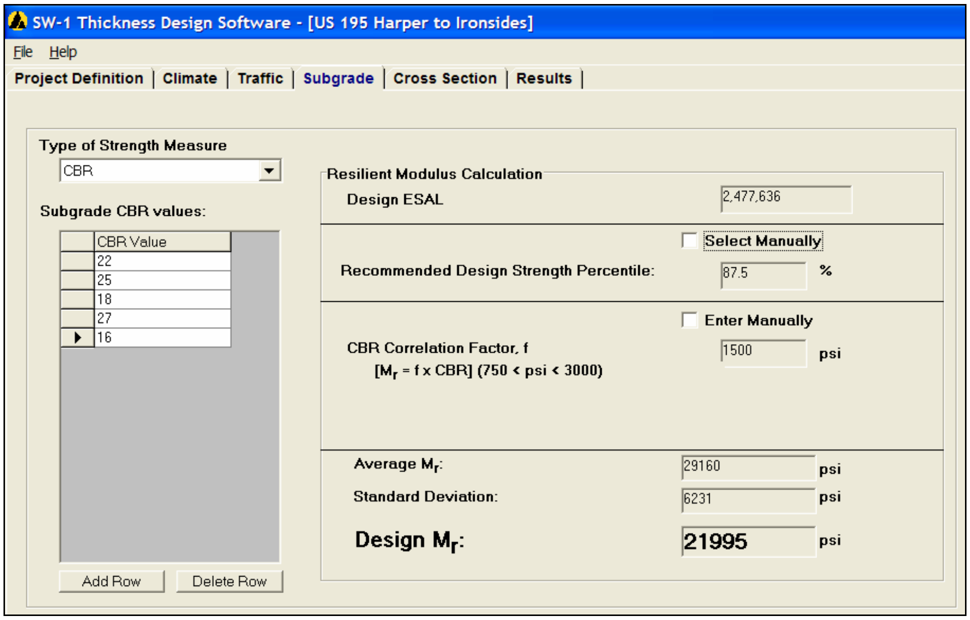
x = average of all data

Z = Z statistic based on the design percentile value

S = sample standard deviation

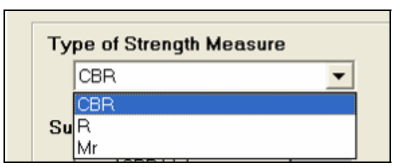
For more detail on selecting design resilient subgrade modulus, please see one of the following AI manuals: MS-1, MS-10, MS-11, MS-17, or MS-23.

Using SW-1 to Enter Subgrade Stiffness Values



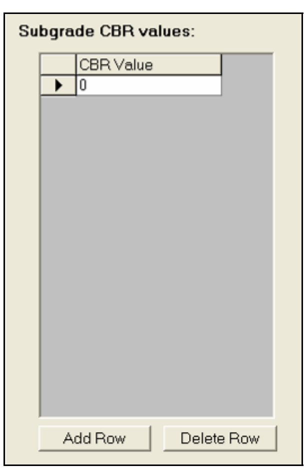
To enter subgrade data

1. Select the type of subgrade strength measure from the drop down list. The three options are CBR, R-value (R), or Resilient Modulus (Mr or M_r).



2. Enter the first subgrade value in the top row of the table.

Note: The name of the table will change depending on the type of strength measure selected in step 1.

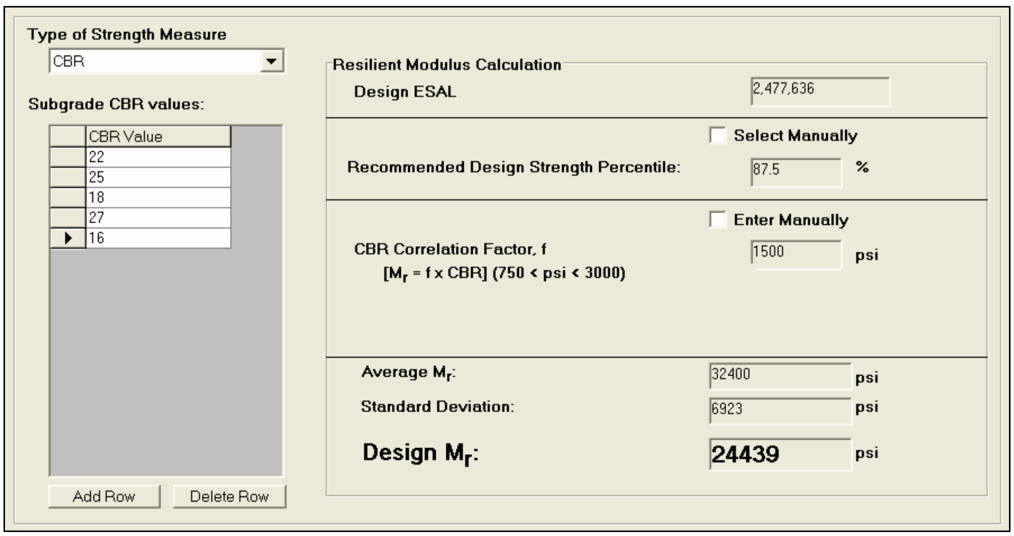


3. To add additional subgrade strength values, select **Add**. This will add a row to the data table. Move to the new row and type in the new value.

4. To delete a value from the data set, place the cursor on the desired row and select **Delete**.

5. Continue to add (or delete) rows and entering data until your data set is complete.

6. For data sets with more than one subgrade strength value, SW-1 automatically calculates the average and standard deviation of the data set and reports them on the screen. Using the design subgrade value (%) defined in the details section of the screen, SW-1 calculates the Design Subgrade Resilient Modulus, which is also reported on the screen.



The Design Subgrade Resilient Modulus is a percentile value of the subgrade resilient modulus test data distribution, which is assumed to be normally distributed. SW-1 automatically recommends a percentile based on the predicted traffic volume. The user can override the recommended selection by clicking **Select Manually** and selecting a percentile level from the drop-down list. Likewise, the user can override the recommended correlation equation by clicking **Enter Manually**.

7. Click **Next**, **Back**, or select another tab.

Note: The **Add** and **Delete** buttons below the subgrade strength value table are used to add or delete rows to the table. The table defaults to having a single row and the user must add additional rows to accept more than one data point. SW-1 automatically calculates the average and standard deviation of the data set as well as the Design Subgrade Resilient Modulus used for the pavement design.

Chapter 6

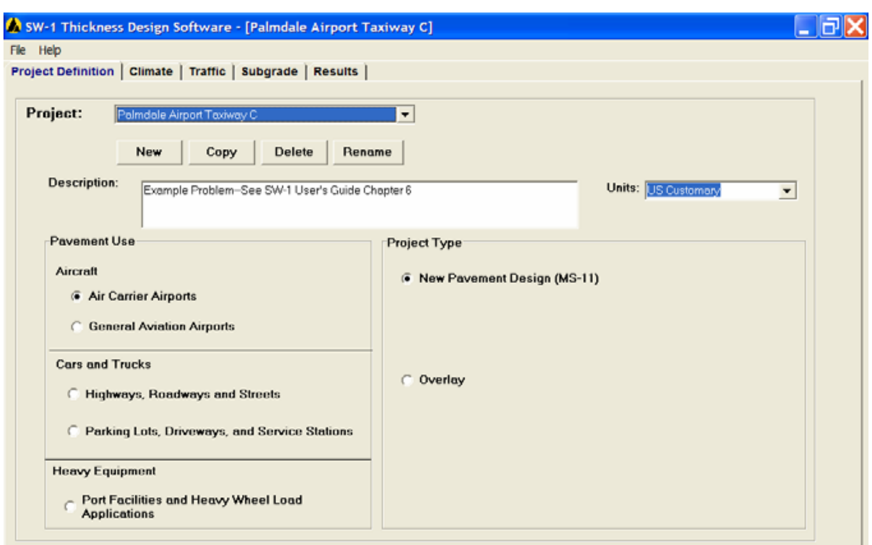
Air Carrier Airports

SW-1 provides the capability to design HMA pavements for air carrier airports that will support heavy commercial aircraft. See the next chapter for information on designing HMA pavements for General Aviation Airports. The comprehensive design manual on this topic is "Thickness Design—Asphalt Pavements for Air Carrier Airports," Manual Series No. 11 (MS-11), which describes this method in full. This method focuses on the design of Full-Depth asphalt pavements for airports serving aircraft of greater than 60,000 lb. gross weight. This method is suitable for new pavement design as well as the design of HMA overlays for existing pavements.

Structural design for air carrier airports requires the following inputs: climate, traffic, and subgrade stiffness. SW-1 uses well-established relationships between mean annual air temperature (MAAT) and pavement thickness in the design process. Traffic analysis is needed to assess the number of strain repetitions that occur at a given critical point within the pavement system. Subgrade stiffness is the key material property used for structural design. The following are specific steps to set up a new air carrier problem.

To design a new pavement or overlay for an Air Carrier Airport

1. Select the Air Carrier Airports radial button under Pavement Use.



2. Select the appropriate radial button under Project Type (New Pavement Design or Overlay).

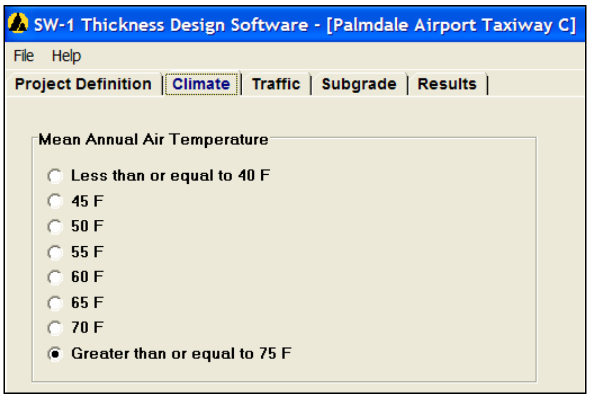
3. Select **Next**

Climate

Temperature affects the response of asphalt materials to loading, and consequently affects the critical strain values calculated under traffic loading. Freezing and thawing conditions also affect the stiffness of supporting unbound base and subgrade materials. More information is provided in Climate on p. 29

For airport pavement design, eight different MAAT classifications are available.

Select the desired MAAT by clicking the appropriate radial button



Traffic

Traffic analysis for airport pavements is a method for estimating the number of strain repetitions that are imposed on pavement section. Strain repetitions imposed on the pavement are a function of the type of aircraft, the gear load, the number of aircraft passes, and the lateral, or transverse wander characteristics of the aircraft on the design area. The optimum or design thickness is the thickness that will allow the pavement to serve, under the strains imposed by the anticipated traffic, for its design period.

Effects on the pavement of strain repetitions of a mixture of different aircraft are considered cumulative. The traffic analysis procedure permits calculating the cumulative effects of traffic at different lateral intervals, x, from the taxiway centerline. This is accomplished by equating the number of strain repetitions produced by the aircraft traffic mixture to a number of equivalent strain repetitions produced by an arbitrarily selected standard aircraft. The standard aircraft is a 358 kip DC-8.

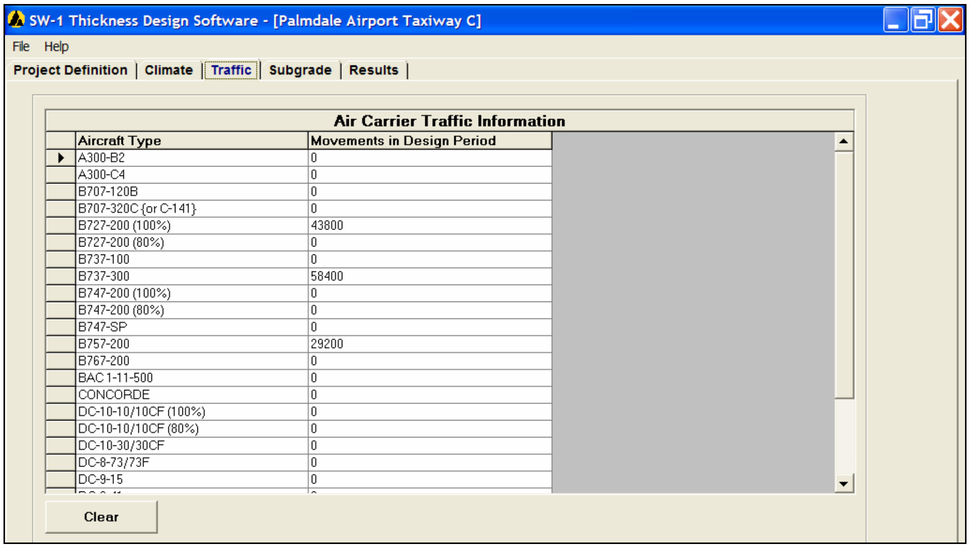
This type of standardization procedure is analogous to the use of 18 kip single-axle load used in highway pavement design.

To enter traffic data for an Air Carrier Airport

1. Find the first aircraft type in the Air Carrier Traffic Information table

2. Enter the number of movements expected during the Design Period for the aircraft in the Movements in the Design Period column.

3. Continue entering traffic data for each aircraft in the design aircraft mix.



Aircraft Type	Movements in Design Period
A300-B2	0
A300-C4	0
B707-120B	0
B707-320C (or C-141)	0
B727-200 (100%)	43800
B727-200 (80%)	0
B737-100	0
B737-300	58400
B747-200 (100%)	0
B747-200 (80%)	0
B747-SP	0
B757-200	29200
B767-200	0
BAC 1-11-500	0
CONCORDE	0
DC-10-10/10CF (100%)	0
DC-10-10/10CF (80%)	0
DC-10-30/30CF	0
DC-8-73/73F	0
DC-9-15	0

Note: The aircraft table in the current version of SW-1 includes the majority of Boeing aircraft, but does not include the Boeing 777. The Asphalt Institute is working to add the Boeing 777 and Airbus 318/319/320, 330, and 340 to future version of SW-1. We apologize for the absence of these aircraft in the current version of our software and look forward to offering them in future versions.

Subgrade

The method for air carrier airports uses the standard inputs for subgrade stiffness as described in Subgrade on p. 33.

Results

When the necessary input values for climate, traffic, and subgrade have been provided by the user, SW-1 makes the **Next** button available to the user on the traffic screen. By clicking on the **Next** button, SW-1 will calculate the results of the pavement design project and create an output report.

For more information on how to review the results of a pavement design, please see Viewing Results on page 25.

Example Problem—Palmdale Airport Taxiway C

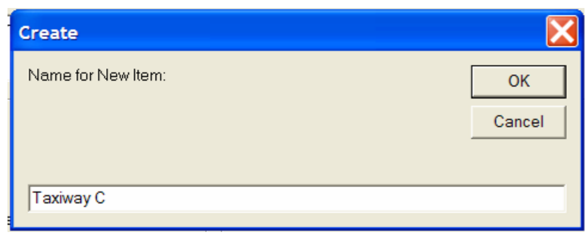
Problem: The Palmdale Airport is a commercial service airport in south Texas that is rapidly expanding. The climate is hot and dry with MAAT = 75ºF. Taxiway C is a new connecting taxiway that is to be constructed of HMA to support the Boeing 727, 737, and 757 aircraft with daily pass levels of 6, 8, and 4, respectively. The Geotechnical Engineer hired by the airport conducted field California Bearing Ratio (CBR) tests along the taxiway alignment in six places and reported the values as shown in Table 4. The design life for the taxiway is 20 years. What is the recommended HMA thickness for a Full-Depth Asphalt section?

Table 4—Subgrade CBR Values for Palmdale Taxiway C

Test No.	CBR
1	12
2	10
3	9
4	13
5	10
6	11

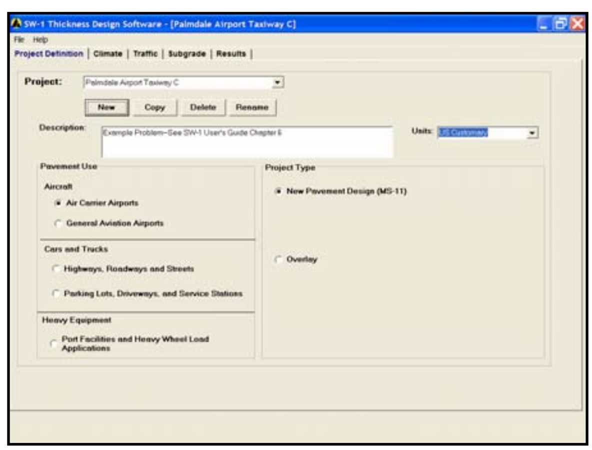
Solution

1. From the Project Definition screen, select **New** to create a new project record and name it **Taxiway C**.



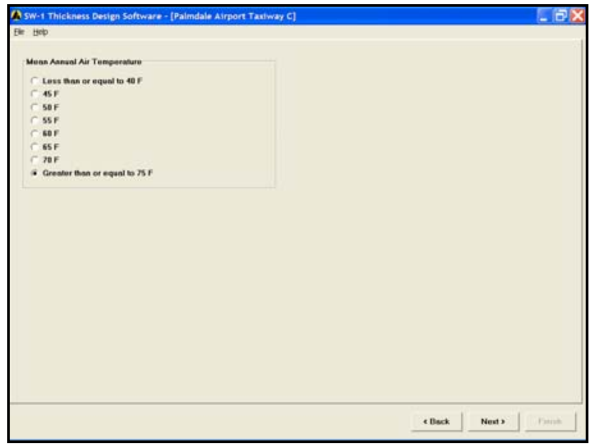
2. While still on the Project Definition screen, select **Air Carrier Airports** in the Pavement Use area and select **New Pavement Design (MS-11)** in the Project Type area. Make sure that **US Customary** units are selected.

3. Click **Next.**



4. On the Climate screen, select **Greater than or equal to 75 F** for MAAT.

5. Click **Next**.



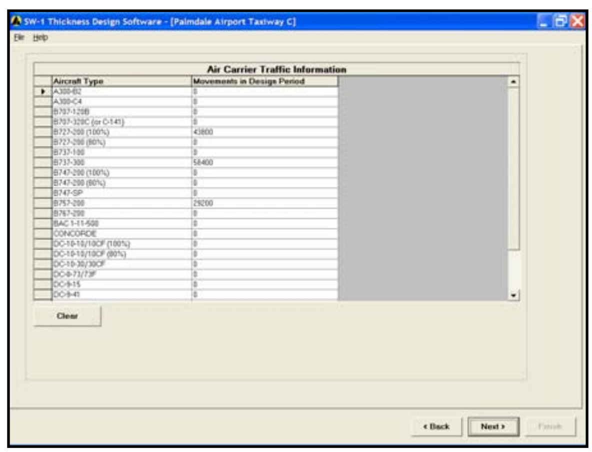
6. Calculate the **Movements in the Design Period** as shown in Table 5.

Table 5—Aircraft Departures for Palmdale Taxiway C Example Problem

Aircraft	Movements		
	Daily	Annual	Design Period (20 Yr)
Boeing 727 100%	6	2,190	43,800
Boeing 737	8	2,920	58,400
Boeing 757	4	1,460	29,200

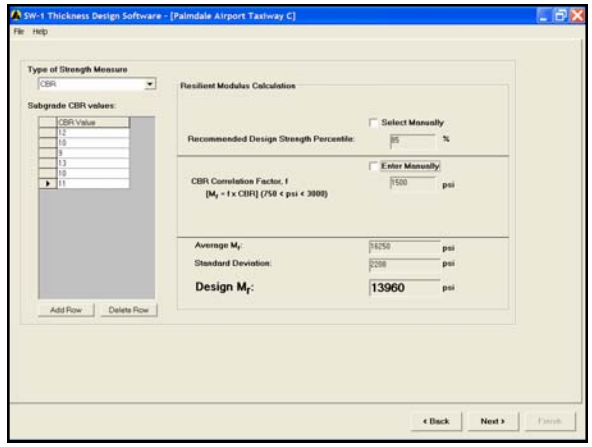
7. On the Traffic screen, enter the **Movements in the Design Period.**

8. Click **Next**.



9. On the Subgrade screen, select CBR as the **Type of Strength Measure** and begin to enter the six **Subgrade CBR Values** from Table 4. Use the **Add** and **Delete** buttons to establish six rows for the input values.

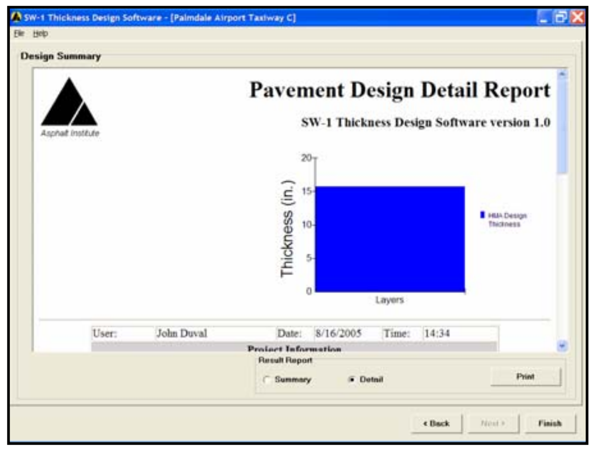
10. Click **Next.**



11. On the Results screen, scroll up or down to view the **Design Summary**.

12. Review the design summary to find that Taxiway C will require a 15.7 inch thick Full Depth Asphalt pavement section to support the desired level of traffic over 20 years.

13. Click **Finish**.



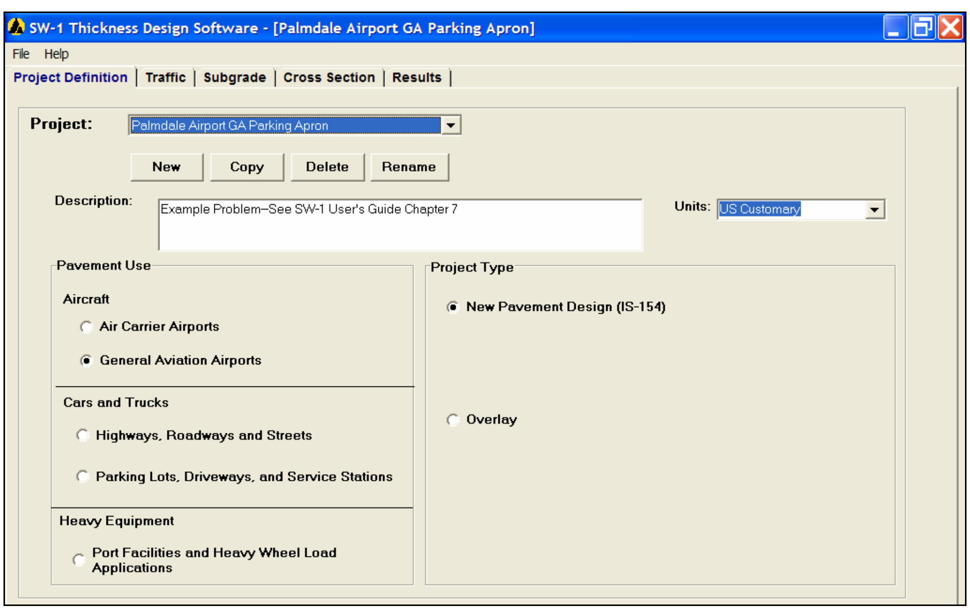
Chapter 7

General Aviation Airports

Pavement design for the nation's 538 primary air carrier airports must deal with heavy commercial jets (gross loads in excess of 60,000 lb.) that impose demanding loads on airfield pavements. There is a vast secondary network of thousands of smaller airports that allow the nation's fleet of general aviation (GA) aircraft to serve local communities throughout the country. These GA aircraft are generally smaller, have gross weights less than 60,000 lb., and place a different set of demands on the pavement systems at GA airports. The GAO describes general aviation as follows:

> "General aviation covers all civil aircraft not flown by commercial airlines or the military. Its tens of thousands of aircraft include corporate jets, medical-evacuation helicopters, and airplanes owned by recreational fliers and hobbyists. Three out of every four takeoffs and landings in the United States belong to general aviation flights." (GAO, 2001)

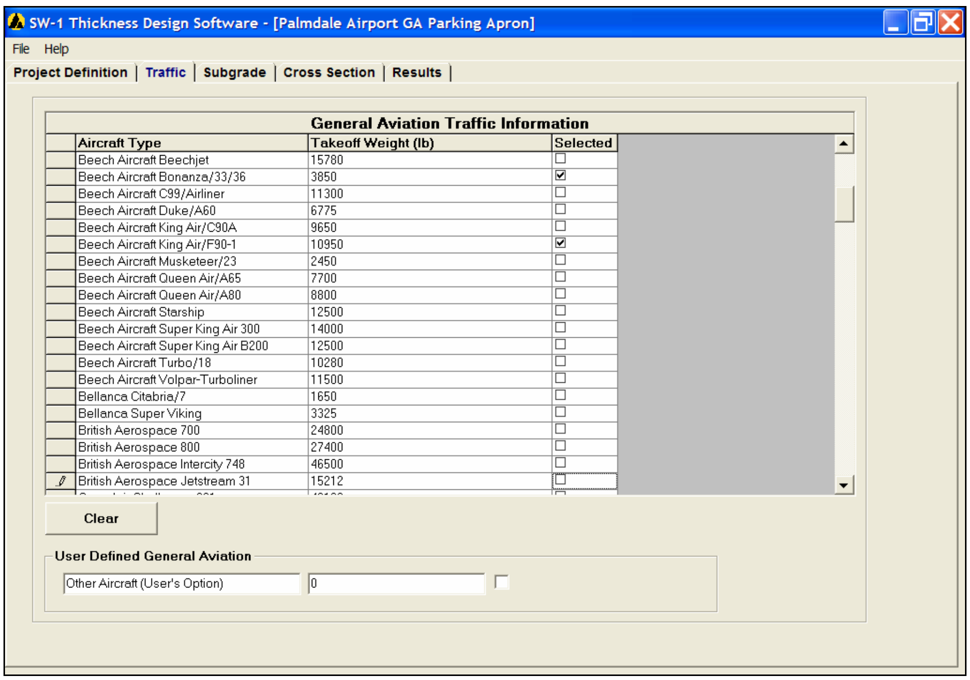
The Asphalt Institute method of thickness design for GA airports is covered in detail in IS-154, *Thickness Design—Asphalt Pavements for General Aviation.* This method, which has been automated by SW-1, requires familiar input values as other AI methods: traffic, subgrade stiffness, and pavement cross section. Design of overlay pavements is accommodated by "borrowing" the effective thickness procedure from MS-17. These topics are described in further detail in this chapter.



Traffic

Note: The simplified thickness design approach in the general aviation airports procedure is limited to asphalt pavements designed to support airplanes having gross weights up to 60,000 lb. If aircraft gross weights in excess of 60,000 lb. are expected, use the method for Air Carrier Airports.

The primary traffic input in this method is the selection of the mix of aircraft in use at a particular airport. From the selected aircraft, SW-1 assigns the aircraft with the highest gross take-off weight as the critical aircraft and uses its gross weight to solve for the pavement design thickness.



To Input Aircraft and Identify the Critical Aircraft

1. On the traffic tab, scroll down the list of aircraft to find the aircraft that operate on the project pavement. Check all that apply.

2. If you do not find a particular aircraft on the list, you can enter it as a User Defined Aircraft. It is important that you accurately input the maximum take-off weight of the aircraft in pounds.

3. When you are finished entering aircraft, click **Back**, **Next** or select another tab. SW-1 will find the critical aircraft and use its gross weight in the remaining calculations.

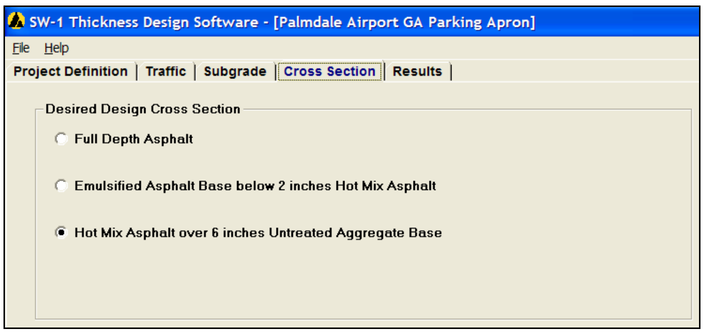
Note: A shortcut is to check only the box for the critical aircraft—if it already known.

Subgrade

The GA airport design method uses the standard inputs for subgrade stiffness as described in Subgrade on p. 33.

Cross Section

In the SW-1 program, you have the ability to select from three general pavement cross-sections: 1) Full-Depth Asphalt, 2) two inches of HMA over a layer of Emulsified Asphalt Base, and 3) HMA over a layer of six inches of Untreated Aggregate Base.



Example Problem—Palmdale Airport GA Parking Apron

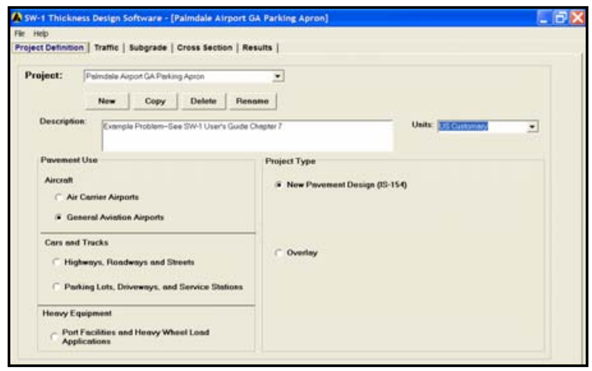
Problem: The Palmdale Airport is planning to construct a new parking apron to support additional general aviation aircraft. The pavement is to be designed for the aircraft shown in Table 6. The Geotechnical Engineer reports that a Design Resilient Modulus for the silty-sand subgrade is 8,500 psi. What is the recommended HMA thickness for a pavement section that incorporates a 6-inch granular base course?

Table 6—GA Aircraft Listing for Palmdale Airport

Aircraft
Beech Bonanza
Beech King Air/F90-1
Cessna 172
Cessna Citation III
Learjet Century III 35
Piper Chieftain

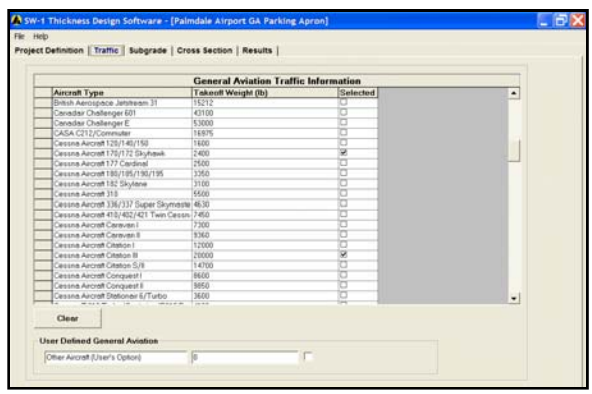
Solution

1. From the Problem Definition screen create a new project record or select an existing project record from the drop-down list.

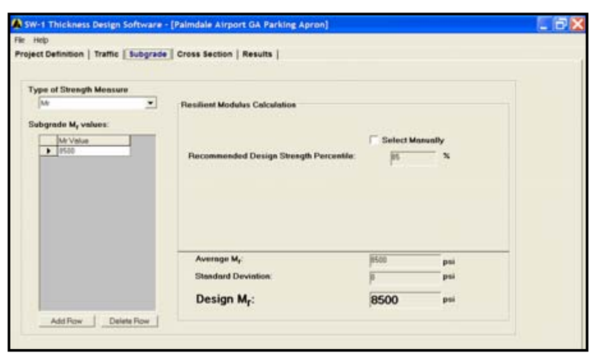


2. Select **General Aviation Airports** under Pavement Use and select **New Pavement Design (IS-154)** under Project Type to define the project.

3. Click on the Traffic tab to reveal the Traffic screen. Select each of the six aircraft types listed in Table 6 by clicking the appropriate box in the **General Aviation Traffic Information** table. You may have to scroll up or down to find them.

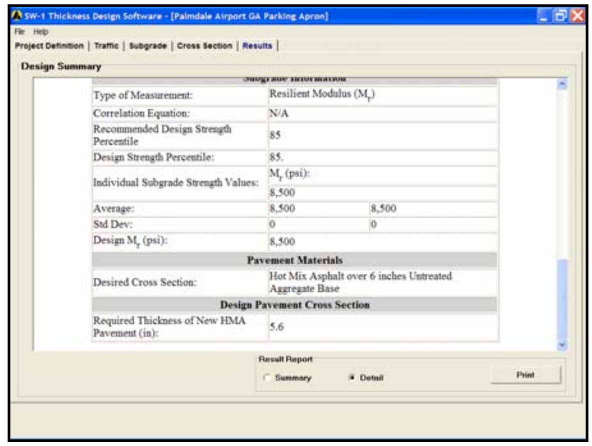


4. Click on the Subgrade tab to reveal the Subgrade screen. Select M_r as the **Type of Strength Measure** and enter a single value of 8,500 psi.



5. Click on the Cross-Section tab to reveal the Cross-Section screen. Select HMA over 6 inches of Untreated Aggregate Base as the **Desired Design Cross-Section**.

6. Click on the Results tab to calculate results and reveal the **Design Summary**. For this problem the calculated HMA thickness is 5.6 inches.



Chapter 8

Highways, Roads, and Streets

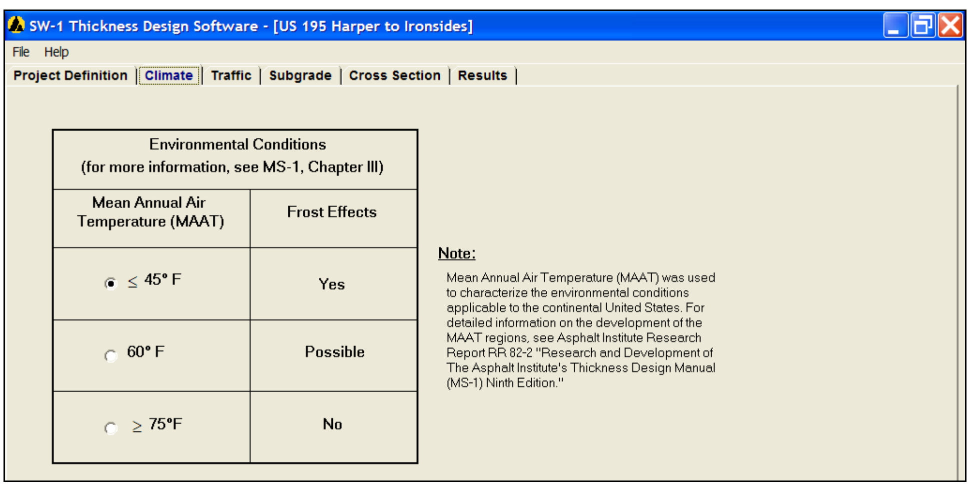
This chapter covers the elements of new pavement design for highways, roads, and streets. Following chapters cover overlay design, two-phase design, planned staged construction, and simplified methods, all methods that applicable to highways, roadways, and streets.

Climate

Temperature affects the response of asphalt materials to loading, and consequently affects the critical strain values calculated under traffic loading. Freezing and thawing conditions also affect the stiffness of supporting unbound base and subgrade materials. More information is provided in Climate on p. 29

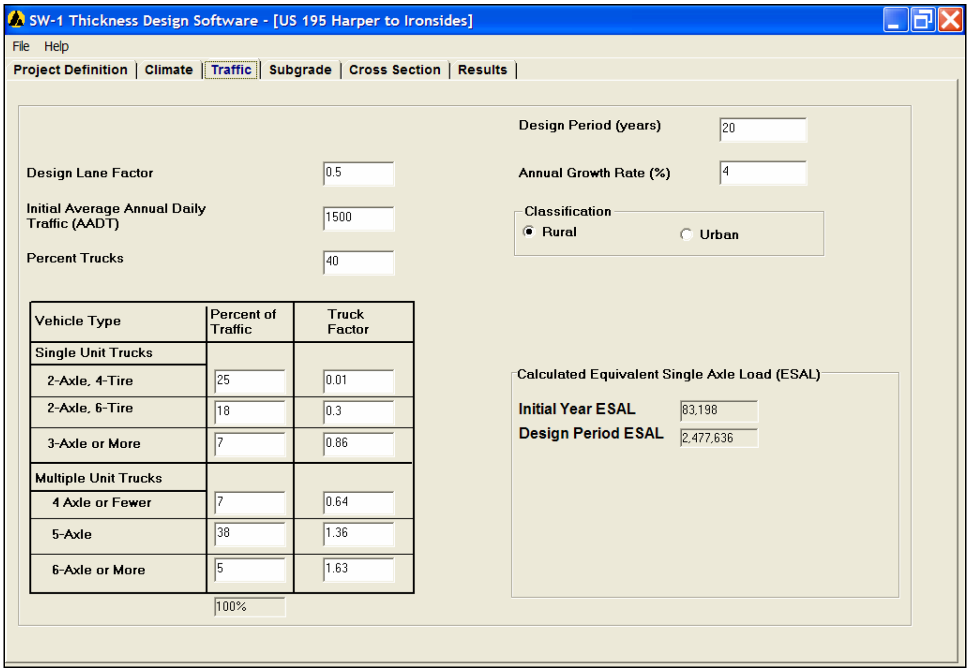
For highway pavement design, three different MAAT classifications are available.

Select the desired MAAT by clicking the appropriate radial button



Traffic

In the SW-1 program, mixed highway and roadway traffic is represented by the number of equivalent 18 kip single-axle load applications, commonly referred to as ESAL.



The number of ESALs expected during a given period of time is a primary concern. The SW-1 traffic tab allows you to estimate the number of ESALs expected on a highway facility over a period of time, using the following equation:

$$\Sigma = (\text{number of vehicles in each weight class}) * (\text{Truck Factor})$$

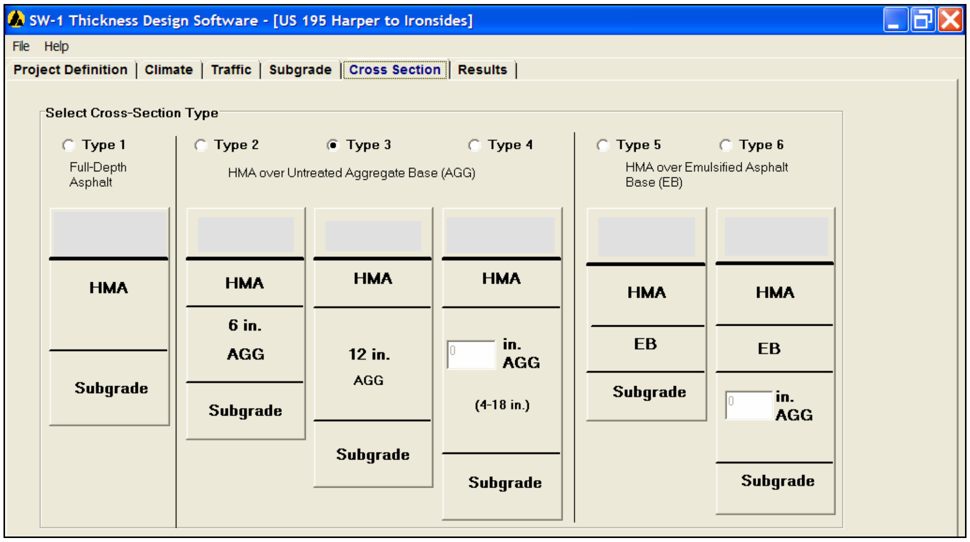
ESAL is calculated by multiplying the number of vehicles in each weight class by the appropriate Truck Factor and summing the products.

Note: The typical Truck Factors were calculated from data summarized by the Federal Highway Administration in 1985.

Subgrade

The method for highways, roads, and streets uses the standard inputs for subgrade stiffness as described in Subgrade on p. 33.

Cross-Section



The Cross-section screen allows the user to specify the combination of materials to be used in the pavement section. There are six cross-section types available in SW-1 as shown in the following table. For types 5 and 6, the user is essentially solving for EB thickness.

Type	Category	Description	Design Objective
1	Full-Depth Asphalt	Hot-mix asphalt (HMA) is employed for **all courses above the subgrade** or improved subgrade	HMA
2	HMA over Aggregate Base	HMA surface course with a **6-inch thick base layer** of unbound aggregate. Minimum HMA thickness is 3 to 4 inches depending on traffic.*	HMA
3		HMA surface course with a **12-inch thick base layer** of unbound aggregate. Minimum HMA thickness is 3 to 4 inches depending on traffic.*	HMA
4		HMA surface course with a **user-defined base layer** of unbound aggregate. Aggregate base thickness can vary from 4 to 18 inches.	HMA
5	HMA over Emulsified Base	HMA is employed as the surface course with **emulsified base (EB)** used as the base material. SW-1 solves for the total thickness required and employs a minimum HMA layer thickness of 2 or 3 inches depending on traffic volume.*	EB
6		HMA is employed as the surface course with **emulsified base (EB)** used as base layer over a **user-defined layer** of unbound aggregate that can vary from 4 to 18 inches. SW-1 solves for the total thickness required and employs a minimum HMA layer thickness of 2 or 3 inches depending on traffic volume.*	EB
* The user is referred to MS-1 for further detail on the relationship between traffic levels and minimum HMA thicknesses for aggregate base and emulsified base problems.			

Example Problem—US Route 195—Harper to Ironsides

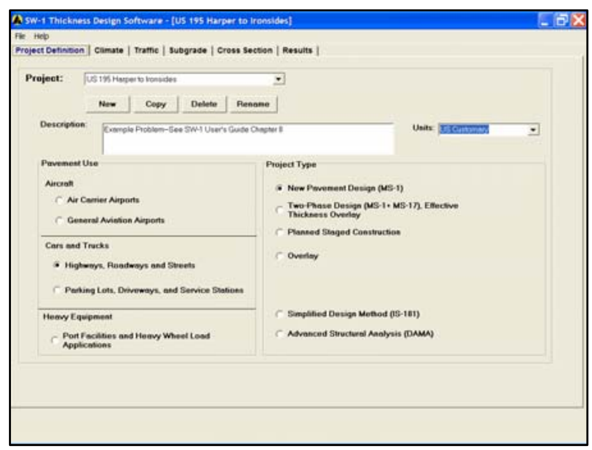
Problem: The Oregon DOT is planning to construct a new two-lane highway between the towns of Harper and Ironsides in the rural eastern part of the state. The climate consists of cold, harsh winters coupled with hot dry summers (MAAT = 45 ºF). Freeze-thaw must be accounted for in any pavement design. Laboratory CBR tests on material from five locations along the route are reported as follows: 22, 25, 18, 27, and 16. (The ODOT pavement designer prefers to use a special CBR Correlation Factor, f = 1,350). Initial traffic volume is only 1,500 AADT, but traffic growth is expected to be rapid—4 percent annually. Trucks account for 40 percent of the traffic on this rural stretch of highway and the truck class percentages are shown in Table 7. Use a design factor of 0.5 and assume a 20-year design period. What is the recommended HMA thickness for a pavement section that incorporates a 12-inch granular base course?

Table 7—Truck Percentages for US 195

Truck Type		Percent of Traffic
Single Unit	2-Axle, 4-Tire	25
	2-Axle, 6-Tire	18
	3-Axle or More	7
Multiple Unit	4-Axle or Fewer	7
	5-Axle	38
	6-Axle or More	5

Solution:

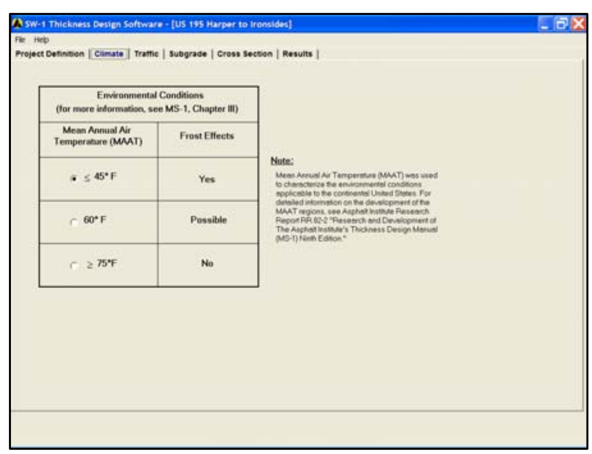
1. Click **New** and create a new project record. Select a **Pavement Use** of Highways, Roadways, and Streets and select New Pavement Design (MS-1) as the **Project Type.**



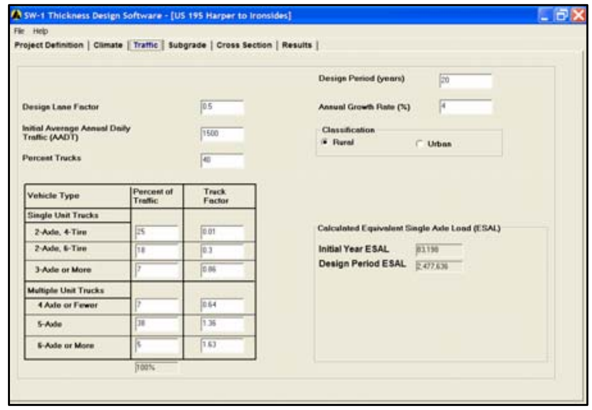
2. Click **Next.**

3. On the Climate screen, select **MAAT** ≤ 45 ºF.

4. Click **Next**.

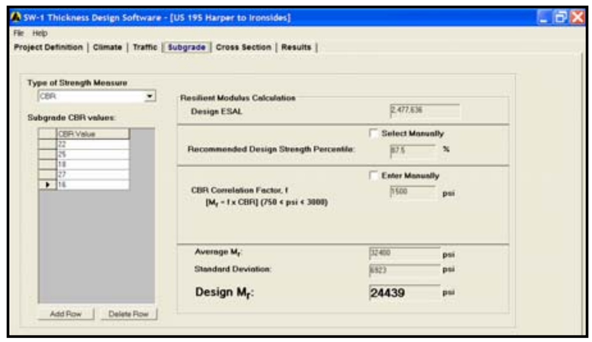


5. On the Traffic screen, enter the data from the Example Problem statement and the truck class percentages from Table 7. The **Design Period** ESAL should show 2,477,636 ESALs over the expected 20-year life.



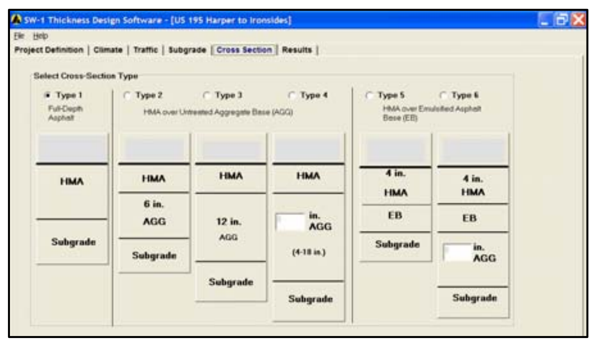
6. Click **Next**.

7. On the Subgrade screen, select CBR for the **Type of Strength Measure** and enter the five CBR values as shown. Make sure the Details box is checked and enter the special correlation factor in the **CBR Correlation Factor, f** box. See that SW-1 has calculated a value of 21,995 psi.



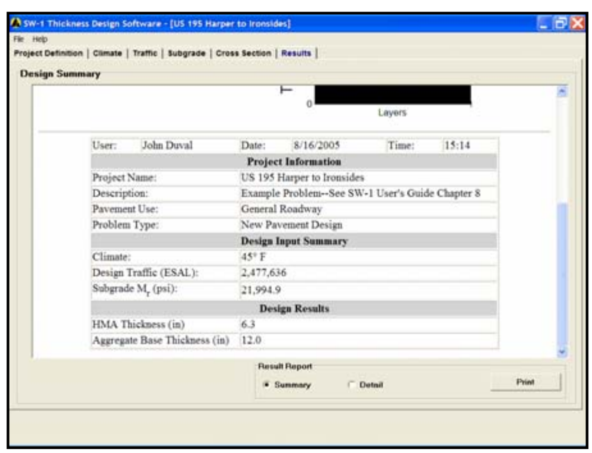
8. Click **Next**.

9. On the Cross-Section screen, select the **Type 3** radial button corresponding to an aggregate base thickness of 12 inches.



10. Click **Next**.

11. View the calculated HMA design thickness of **6.3 inches**.



12. Click **Finish** to reveal the screen tabs.

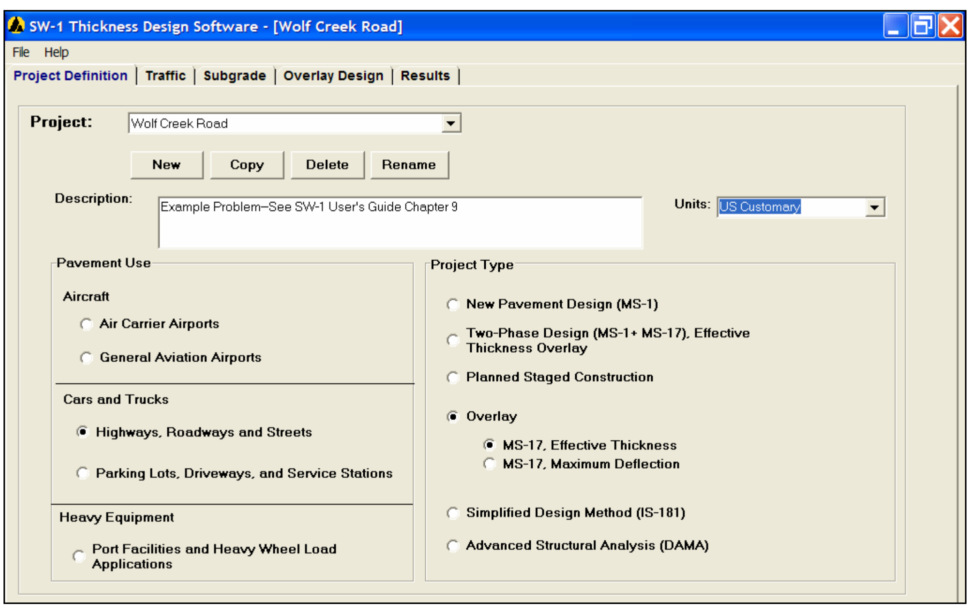
Chapter 9

Overlay Design

Design of HMA overlays is based on either the effective thickness or the deflection method as detailed in Asphalt Institute Manual MS-17.

Effective Thickness Method

The effective thickness procedure for structural evaluation and overlay design is based on the concept that pavements deteriorate. In other words, their service life has been reduced after exposure to traffic for extended periods of time. In effect, a pavement "uses" part of its total life as a result of load repetitions imposed by traffic. By the time distress conditions appear on the surface of the pavement a certain amount of the useful life of the pavement has been used and must be accounted for in the design process. At the same time, the "remaining life" of the existing pavement can be utilized in designing the pavement for future conditions.



The procedure assumes that as a pavement uses part of its total life, it behaves as if it were an increasingly thinner pavement, i.e., its effective thickness becomes less and less to account for the expended portion of the total life of the pavement.

To calculate the effective thickness of an existing pavement, it is necessary to know the composition, thickness and condition of each pavement layer. It is also necessary to obtain an estimate of future traffic (ESALs) following the HMA overlay. Finally, the thickness computation of a new, full-depth asphalt pavement is based on identified subgrade strength and ESALs. The overlay thickness is the difference between the thickness for a new pavement and the effective thickness of the existing pavement.

Estimating Effective Thickness from Pavement Condition

With this method, the condition of the pavement layers is determined and appropriate conversion factors are selected from Table 8-1. The effective thickness of each layer is the product of the actual thickness of each layer and the appropriate conversion factor. The effective thickness of the total pavement structure is the sum of the effective thickness values of all layers, or:

$$T_e = \Sigma\, T_i C_i$$

where:

T_e = effective thickness

T_i= actual thickness of each layer

C_i = conversion factor

Available equivalency performance data on materials are insufficient to set specific conversion factors. Thus, the conversion factors in Table 8, encompassing most paving materials, are in some degree subjective. Although the ranges in values shown are based on a subjective analysis, experience has shown that they are reasonable and useful for overlay design.

Calculation of Overlay Thickness

The effective thickness overlay design procedure given in SW-1 makes use of the following relationship:

$$T_o = T_n - T_e$$

where:

T_o = Thickness of overlay

T_n = Thickness that a new pavement (after overlay) would require for expected traffic and subgrade conditions.

T_e = Effective thickness of the existing pavement structure

Table 8—Conversion Factors for Effective Thickness Method

<table>
<tr><th colspan="4">Conversion Factors for Converting Thickness of Existing Pavement Components to Effective Thickness (T_e) (After MS-17 Table 8-1)</th></tr>
<tr><th>Classification</th><th colspan="2">Description of Material</th><th>Conversion Factor</th></tr>
<tr><td rowspan="3">I</td><td>a</td><td>Native subgrade in all cases.</td><td rowspan="3">0.0</td></tr>
<tr><td>b</td><td>Improved Subgrade - predominately granular materials - may contain some silt and clay but have P.I. of 10 or less.</td></tr>
<tr><td>c</td><td>Lime treated subgrade constructed from high plasticity soils - P.I. greater than 10</td></tr>
<tr><td>II</td><td></td><td>Granular subbase or base—reasonably well-graded hard aggregates with some plastic fines and CBR not less than 20. Use upper part of range if P.I. is 6 or less; lower part of range if P.I. is more than 6.</td><td>0.1 - 0.2</td></tr>
<tr><td>III</td><td></td><td>Cement or lime-fly-ash stabilized subbases and bases constructed from low plasticity soils - P.I. of 10 or less.</td><td>0.2 - 0.3</td></tr>
<tr><td rowspan="3">IV</td><td>a</td><td>Emulsified or cutback asphalt surfaces and bases that show extensive cracking, considerable raveling or aggregate degradation, appreciable deformation in the wheel paths, and lack of stability.</td><td rowspan="3">0.3 - 0.5</td></tr>
<tr><td>b</td><td>Portland cement concrete pavements (including those under asphalt surfaces) that have been broken into small pieces (2 feet or less in maximum dimension [0.6 meters]) prior to overlay construction. Use upper part of range when subbase is present; lower part of range when slab is on subgrade.</td></tr>
<tr><td>c</td><td>Cement or lime-fly-ash stabilized bases that have developed pattern cracking, as shown by reflected surface cracks. Use upper part of range when cracks are narrow and tight; lower part of range with wide cracks, pumping or evidence of instability.</td></tr>
<tr><td rowspan="2">V</td><td>a</td><td>Rubblization</td><td>0.3 - 0.6</td></tr>
<tr><td>b</td><td>Crack/Break and Seat (when unstabilized base is present, use lower end of range. When stabilized base is present, use upper end of range.)</td><td>0.5 - 0.7</td></tr>
<tr><td rowspan="3">VI</td><td>a</td><td>Asphalt concrete surface and base that exhibit appreciable cracking and crack patterns.</td><td rowspan="3">0.5 - 0.7</td></tr>
<tr><td>b</td><td>Emulsified or cutback asphalt surface and base courses that, although remain stable, exhibit some fine cracking, raveling, or aggregate degradation, and slight deformation in the wheel paths.</td></tr>
<tr><td>c</td><td>Appreciably cracked and faulted portland cement concrete (PCC) pavement (including those previously overlaid with HMA) that cannot be effectively undersealed. Slab fragments that range in size from 1 to 4 square meters, and have been well seated on the subgrade by heavy pneumatic-tired rolling.</td></tr>
<tr><td rowspan="3">VII</td><td>a</td><td>HMA surfaces and bases that exhibit some fine cracking; have small intermittent cracking patterns; and have slight deformation in the wheel paths but remain stable</td><td rowspan="3">0.7 - 0.9</td></tr>
<tr><td>b</td><td>Emulsified or cutback asphalt surface and bases that are stable, generally uncracked, show no bleeding, and exhibit little deformation in the wheel paths.</td></tr>
<tr><td>c</td><td>Portland cement concrete pavements (including those under HMA) that are stable and undersealed, have some cracking but contain no pieces smaller than about one square meter.</td></tr>
<tr><td rowspan="2">VIII</td><td>a</td><td>Hot-mix asphalt, including HMA base, generally uncracked and with little deformation in the wheel paths.</td><td rowspan="2">0.9 - 1.0</td></tr>
<tr><td>b</td><td>Portland cement concrete base, under HMA surface, that is stable, non-pumping and exhibits little reflected surface cracking.</td></tr>
</table>

Example Problem—Wolf Creek Road

Problem: The Lane County Public Works Department is planning to overlay a two-lane rural county road between the towns of Cougar and Westfir high in the Cascade mountain range. The existing road is constructed of 3 inches HMA over 6 inches aggregate base. Subgrade soils along the route are consistent with M_r = 7,000 psi. The pavement design consultant does not have access to any deflection data and decides to use the Effective Thickness method for overlay design. A pavement condition survey reveals that the existing HMA surface shows some light cracking and minor wheel path rutting. Traffic volume is 1,100 AADT growing at 1.5 percent annually. Trucks account for 22 percent of the traffic with the truck class percentages shown in Table 9. Use a design factor of 0.5 and assume a 20-year design period. What is the recommended HMA overlay thickness?

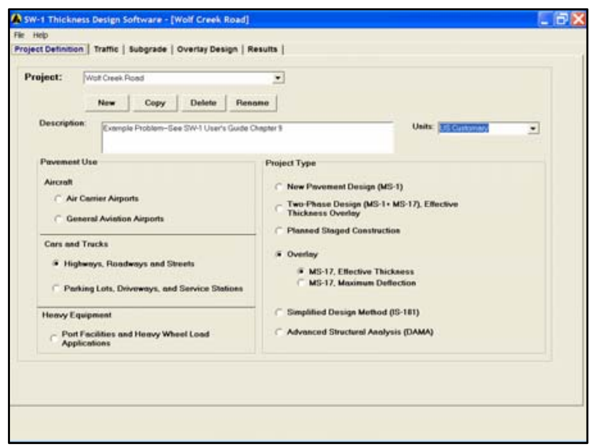
Table 9—Truck Percentages for WCR

Truck Type		Percent of Traffic
Single Unit	2-Axle, 4-Tire	24
	2-Axle, 6-Tire	8
	3-Axle or More	6
Multiple Unit	4-Axle or Fewer	6
	5-Axle	52
	6-Axle or More	4

Solution:

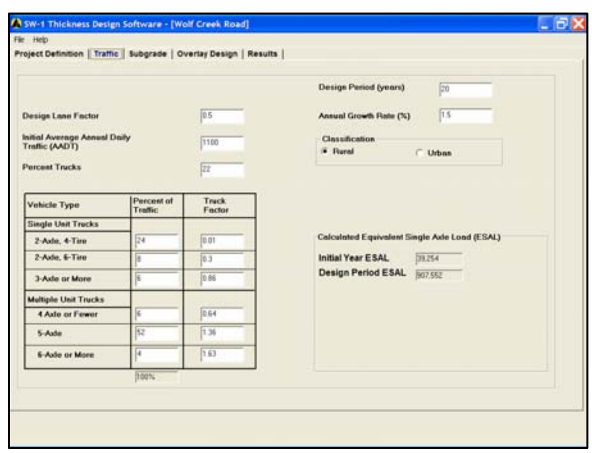
1. Click **New** and create a new project record. Select a **Pavement Use** of Highways, Roadways, and Streets and select Overlay as the **Project Type.** Check the box next to MS-17, Effective Thickness

2. Click **Next.**



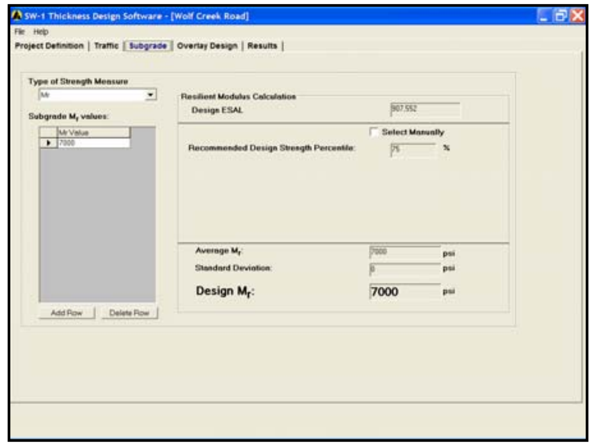
3. On the Traffic screen, enter the data from the Example Problem statement and the truck class percentages from Table 9.

4. Click **Next**.



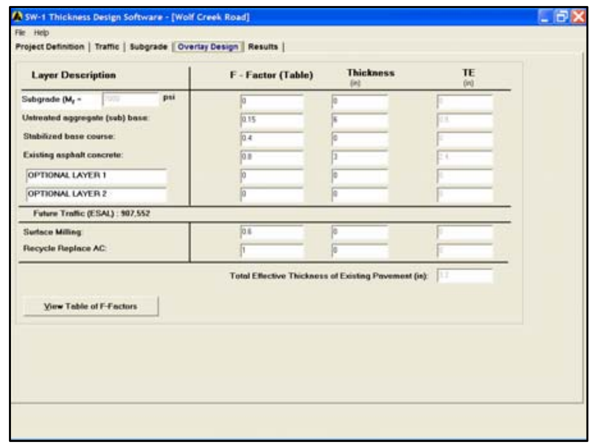
5. On the Subgrade tab select M_r for the **Type of Strength Measure** and enter the single M_r value.

6. Click **Next**.



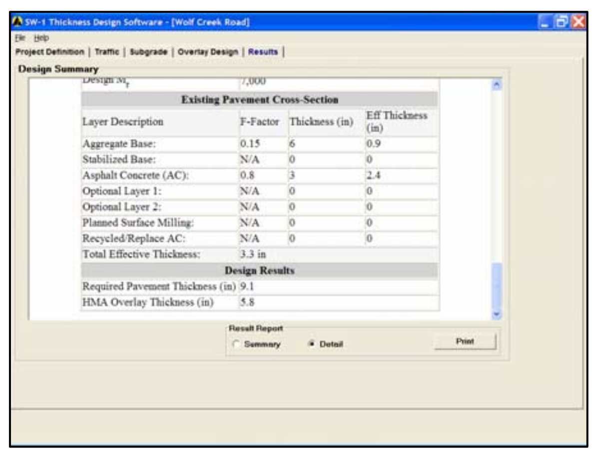
7. On the Overlay screen, enter the **F-Factor** and **Thickness** of the existing section. (In this case, the consultant decides to use F-Factors of 0.15 for aggregate base and 0.8 for the existing HMA, respectively.) Note that SW-1 calculates and displays the effective thickness of individual layers and that of the total existing section.

8. Click **Next**.



9. View the calculated overlay design thickness of **5.8 inches**.

10. Click **Finish** to reveal the screen tabs and perform comparative analyses.



Maximum Deflection Method

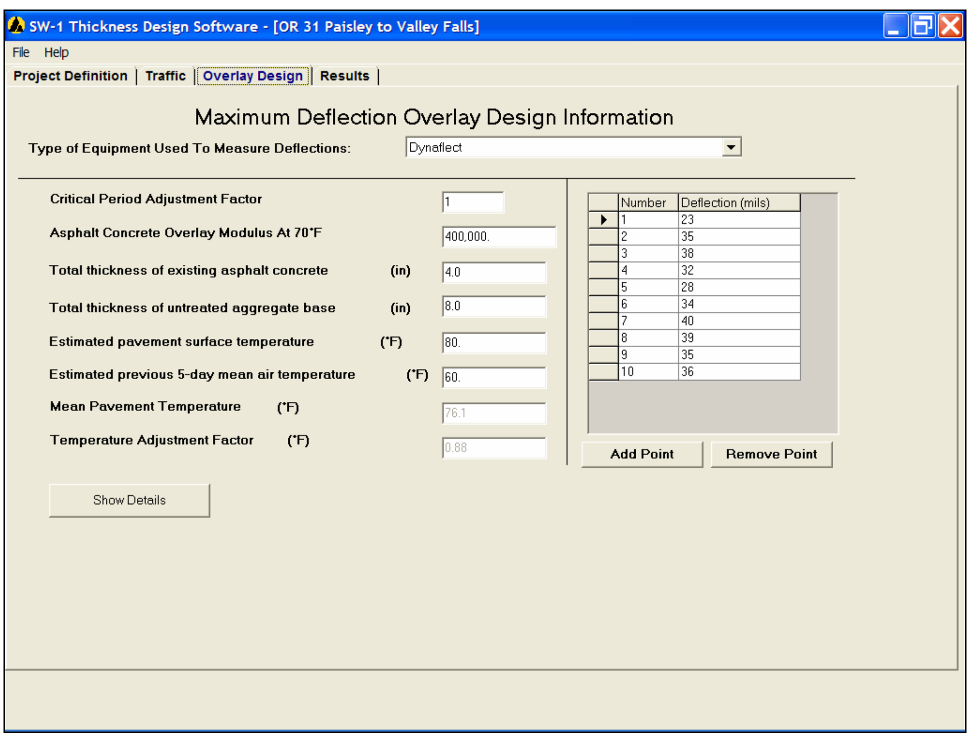
The Asphalt Institute deflection-based design methods for flexible pavements and rigid pavements have been established over many years of successful application. The method is based on the analysis of Benkelman Beam data. In the maximum deflection method, you can also use data from a dynamic or impulse load NDT device such as the Dynaflect, Road Rater and falling weight deflectometer (FWD).

The deflection procedure for flexible pavements is an empirical method, which uses an actual Representative Rebound Deflection (RRD) from the Benkelman Beam device, or an equivalent RRD from dynamic or impulse nondestructive test device. The magnitude of the deflection is an indicator of the structural capacity of the existing pavement and its ability to accommodate future traffic loading. The deflection data is used to evaluate whether a strengthening overlay is indeed necessary, and if so, to design the overlay thickness. Overlay thickness is designed to reduce pavement deflections from a measured to a limiting design RRD for varying traffic conditions.

As with flexible pavements, the rigid pavement deflection method is also empirically based, whereby actual or equivalent RRDs are measured and compared to limiting values for jointed and continuous reinforced concrete pavement.

Overlay Design Inputs

The maximum deflection overlay design procedure requires detailed information that is covered in detail in Asphalt Institute Manual MS-17 "Asphalt Overlays for Highway and Street Rehabilitation." Readers are referred to MS-17 for details on this method.

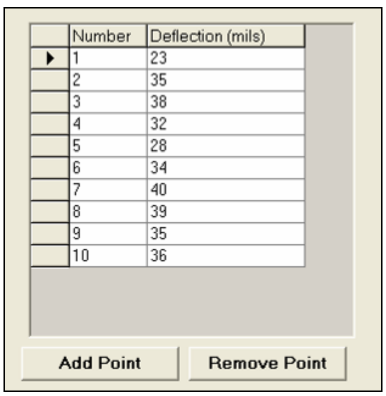


<u>Deflection Points</u>

The SW-1 program has the capability to conduct a deflection analysis using deflection points acquired by four types of deflection equipment:

- Benkleman Beam
- Dynaflect
- Road Rater
- Falling Weight Deflectometer

Deflection data is entered manually in SW-1 after selecting the appropriate type of equipment from the drop-down list.



Number	Deflection (mils)
1	23
2	35
3	38
4	32
5	28
6	34
7	40
8	39
9	35
10	36

Once all the desired deflection points have been entered, overlay calculation is completed by clicking on the Results tab.

Example Problem—OR 31—Paisley to Valley Falls

Problem: The Oregon DOT recently conducted falling weight deflectometer testing on a section of OR 31 between Paisley and Valley Falls for the purpose of overlay design using the Maximum Deflection method. The existing road is constructed of 4 inches HMA over 8 inches aggregate base. Traffic volume is 1,500 AADT growing at 2 percent annually. Trucks account for 28 percent of the traffic with the truck class percentages shown in Table 10. FWD deflection tests are shown in Table 11. Use a stiffness of 400,000 psi for the modulus of HMA at 70 ºF.

Table 10—Truck Percentages for OR 31

Truck Type		Percent of Traffic
Single Unit	2-Axle, 4-Tire	30
	2-Axle, 6-Tire	12
	3-Axle or More	4
Multiple Unit	4-Axle or Fewer	6
	5-Axle	42
	6-Axle or More	6

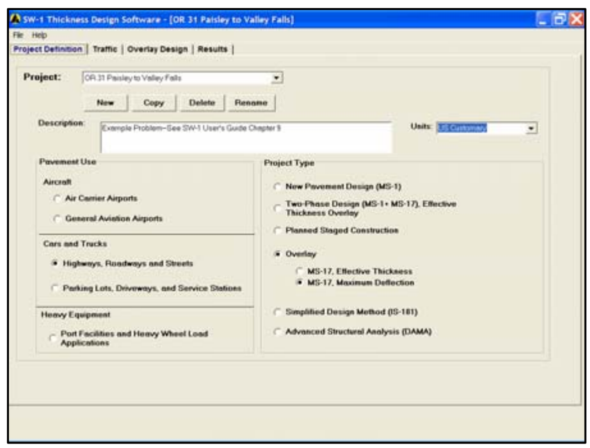
Table 11—Deflection Points for OR 31

Test No.	Deflection (mil)	Test No.	Deflection (mil)
1	23	6	34
2	35	7	40
3	38	8	39
4	32	9	35
5	28	10	36

Solution:

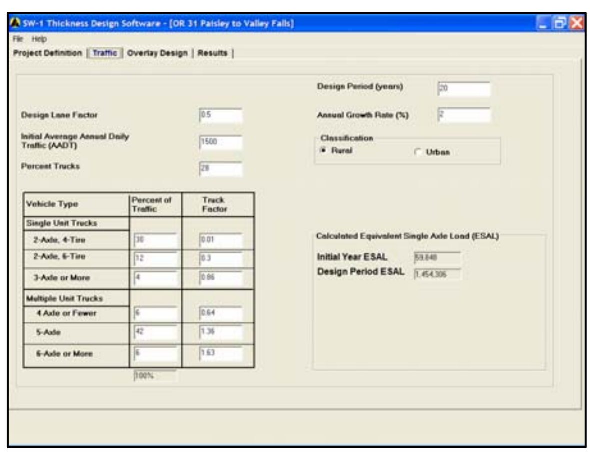
1. Click **New** and create a new project record. Select a **Pavement Use** of Highways, Roadways, and Streets and select Overlay as the **Project Type.** Check the box next to MS-17, Maximum Deflection

2. Click **Next.**



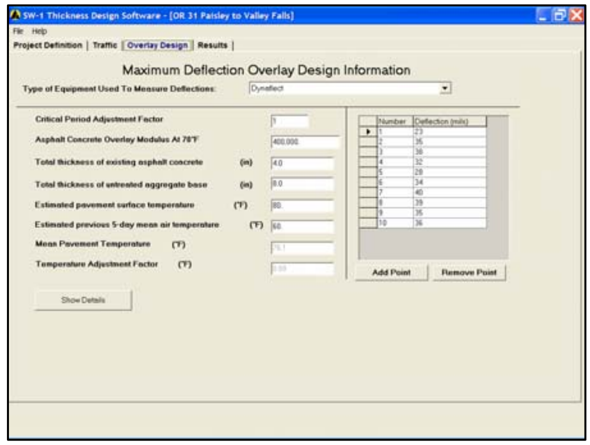
3. On the Traffic screen, enter the data from the Example Problem statement and the truck class percentages from Table 10.

4. Click **Next**.



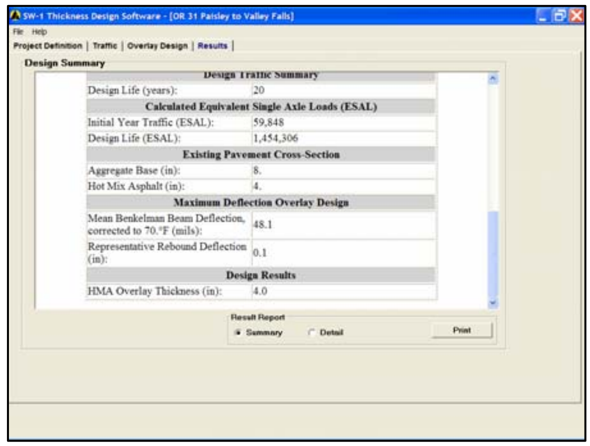
5. On the Overlay Design screen select enter the required information. Select FWD as the **Type of Equipment** and begin entering individual deflection points. Use the **Add Point** and **Remove Point** buttons to adjust the number of rows available for deflection point data

6. Click **Next**.



7. On the Results screen, view the calculated overlay design thickness of **4 inches**.

8. Click **Finish** to reveal the screen tabs and perform comparative analyses.



Two-Phase Design

SW-1 includes the capability to design initial construction and subsequent rehabilitation over extended analysis periods. This capability is especially important when developing design alternatives and comparing life-cycle costs over time. Two-phase design uses the procedures detailed in MS-1 and MS-17 coupled into a single design effort.

Note: Two-phase design differs significantly in concept from Planned Staged Construction, which is discussed in the next chapter of this User's Guide.

The primary difference between a two-phased design problem and New Pavement Design in a single stage is that an analysis period must be established. The analysis period must be equal to or longer than the structural design period and is typically between 30 and 40 years. See Figure 4 for a visual depiction of this concept.

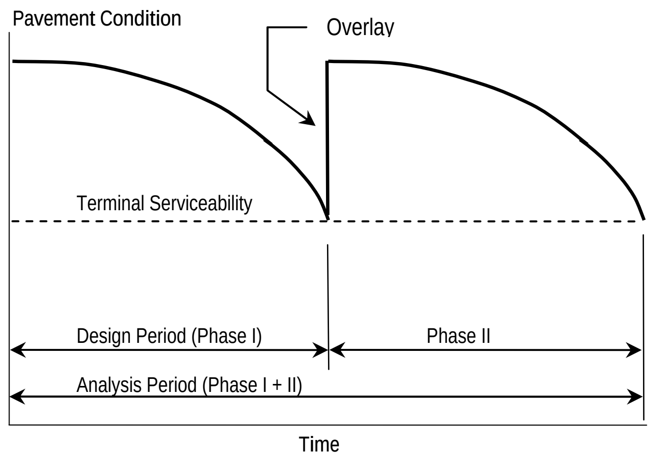


Figure 4—Two-Phase Design Concept

The design inputs for a two-phase design are the same as those for traditional design of new pavements and overlays. Climate, traffic, and subgrade inputs must be entered along with cross-section and overlay conversion factors. The following example problem illustrates the concept.

Example Problem—Mill Plain Boulevard

Problem: The City of Vancouver is planning to reconstruct Mill Plain Boulevard using a two-phase design using Full-Depth Asphalt. The design period is 20 years and the analysis period is 40 years. Mill Plain Blvd. has four traffic lanes (two in each direction). Use a design lane factor of 0.4. Initial AADT is 5,000 with 8 percent trucks. Truck classifications are shown in Table 12. Traffic growth is projected at 1.0 percent annually in this urban area. The MAAT for Vancouver is approximately 60ºF and the subgrade soil resilient modulus has been established as 10,000 psi. What is the recommended pavement thickness for initial construction and the overlay?

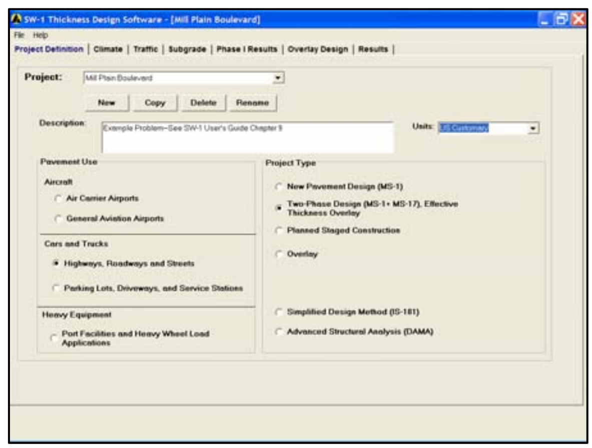
Table 12—Truck Percentages for MPB

Truck Type		Percent of Traffic
Single Unit	2-Axle, 4-Tire	63
	2-Axle, 6-Tire	12
	3-Axle or More	4
Multiple Unit	4-Axle or Fewer	2
	5-Axle	18
	6-Axle or More	1

Solution:

1. Click **New** and create a new project record. Select a **Pavement Use** of Highways, Roadways, and Streets and select Two-Phase Design (MS-1 + MS-17) as the **Project Type.**

2. Click **Next.**

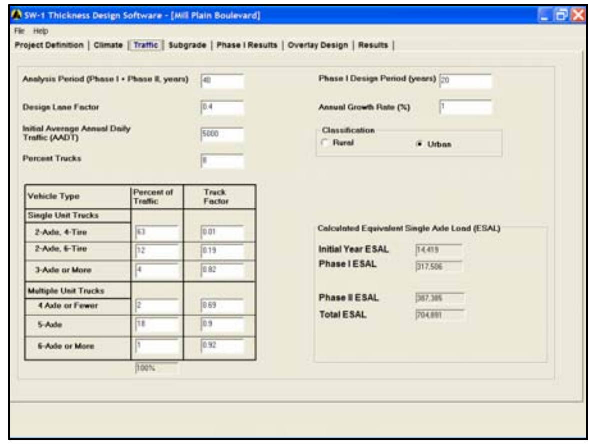


3. On the Climate screen, select **MAAT** = 60ºF

4. Click Next.

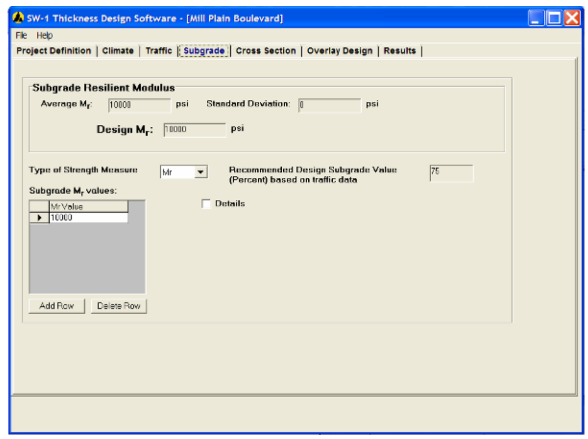
5. On the Traffic screen, enter the data from the Example Problem statement and the truck class percentages from Table 12. The Design Period ESALs are calculated to be 317,506 and the Remaining ESALs are 387,385.

6. Click **Next**.



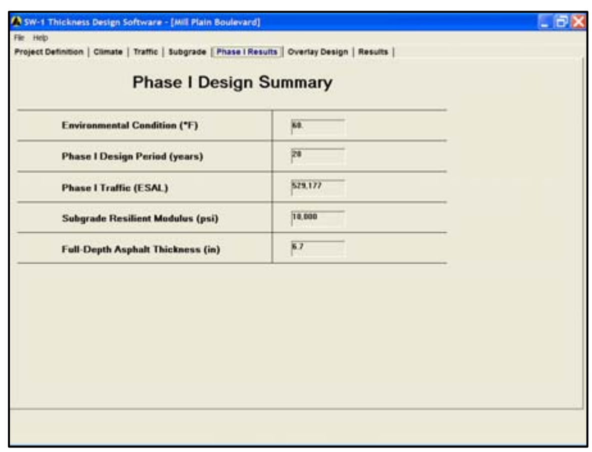
7. On the Subgrade screen, select **Type of Strength Measure** as M_r and enter 10,000 as the Subgrade M_r value.

8. Click **Next**.

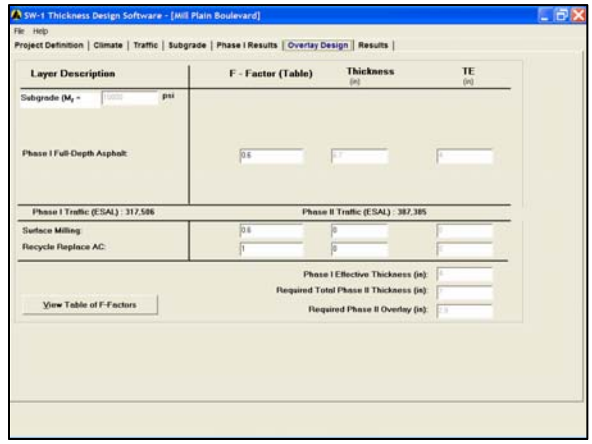


9. View the results for the Phase I Design Summary to show a Full Depth Asphalt thickness of 6.7 inches.

10. Click **Next**.



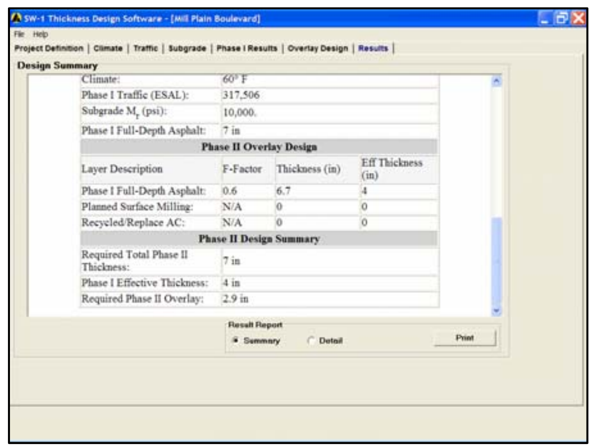
11. On the Overlay Design screen note that the existing HMA thickness is entered under Phase I Full Depth Asphalt. Use the default F-Factor of 0.6 for HMA. (A table of F-Factors is available for viewing.) Note the effective thickness of the Phase I layer is 4.0 inches.



12. Click **Next**.

13. On the Results tab scroll down to see that the calculated overlay thickness for Phase II is 2.9 inches.

14. Click **Finish** to reveal the screen tabs and perform comparative analyses.



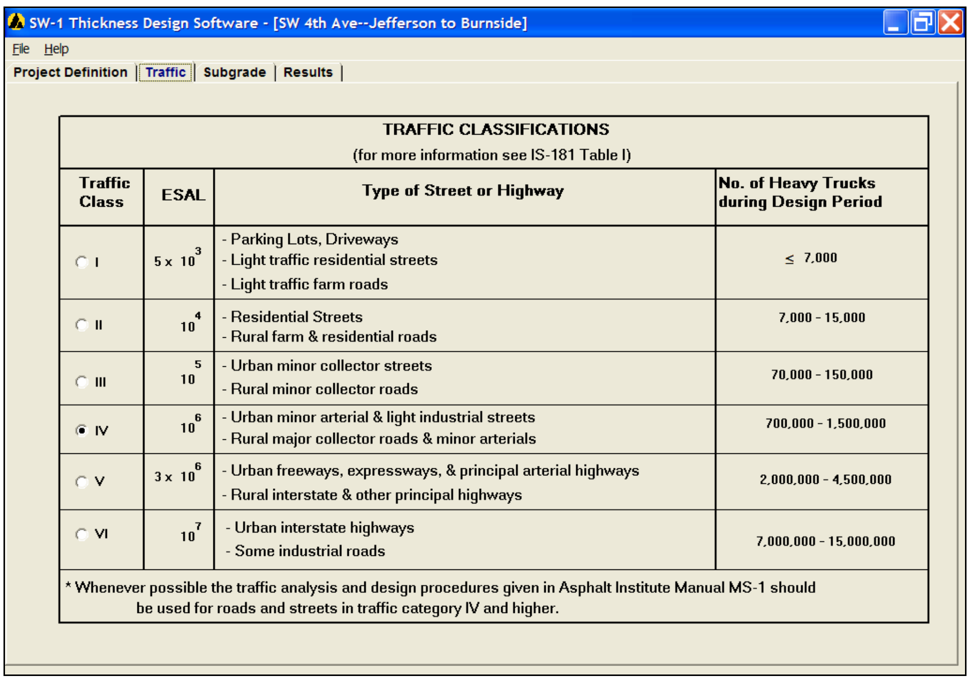
Simplified Method

As its name states, the simplified method reduces some of the complexity of the standard design method for highways, roadways, and streets. It is based on the procedure detailed in Information Series No. 181 (IS-181).

The simplified method contains design information for a range of traffic conditions for urban streets and rural highways, for difference subgrade conditions and for pavements constructed of asphalt concrete, with emulsified asphalt mixtures, and with untreated aggregate base and subbase materials. There is no consideration of environmental conditions in the simplified method.

Traffic:

In the simplified method, traffic is broken down into six classes. Each class is associated with a particular equivalent number of ESALs, the type of highway or street, and the average daily number of heavy trucks expected on the facility during the design period. So, rather than estimating the percentage of trucks and truck classes, the simplified method asks the user to estimate traffic volume within a range.



TRAFFIC CLASSIFICATIONS
(for more information see IS-181 Table I)

Traffic Class	ESAL	Type of Street or Highway	No. of Heavy Trucks during Design Period
I	5×10^3	- Parking Lots, Driveways - Light traffic residential streets - Light traffic farm roads	≤ 7,000
II	10^4	- Residential Streets - Rural farm & residential roads	7,000 - 15,000
III	10^5	- Urban minor collector streets - Rural minor collector roads	70,000 - 150,000
IV	10^6	- Urban minor arterial & light industrial streets - Rural major collector roads & minor arterials	700,000 - 1,500,000
V	3×10^6	- Urban freeways, expressways, & principal arterial highways - Rural interstate & other principal highways	2,000,000 - 4,500,000
VI	10^7	- Urban interstate highways - Some industrial roads	7,000,000 - 15,000,000

* Whenever possible the traffic analysis and design procedures given in Asphalt Institute Manual MS-1 should be used for roads and streets in traffic category IV and higher.

Subgrade Soils

In the simplified method, subgrade soil strength is assigned to one of three categories based on the evaluation of an engineer knowledgeable with the local conditions. The three categories are:

Poor Subgrade Soils: These soils become quite soft and plastic when wet. Included are those soils having appreciable amounts of clay and fine silt. The coarser silts and sandy loams also may exhibit poor bearing properties in areas where frost penetration into the subgrade is a factor. **Typical properties: M_r = 4,500 psi, CBR = 3, and R-value = 6.**

Medium Subgrade Soils: These soils retain a moderate degree of firmness under adverse moisture conditions. Included are such soils as loams, silty sands, and sand-gravels containing moderate amounts of clay and fine silt. **Typical properties: M_r = 12,000 psi, CBR = 8, and R-value = 20.**

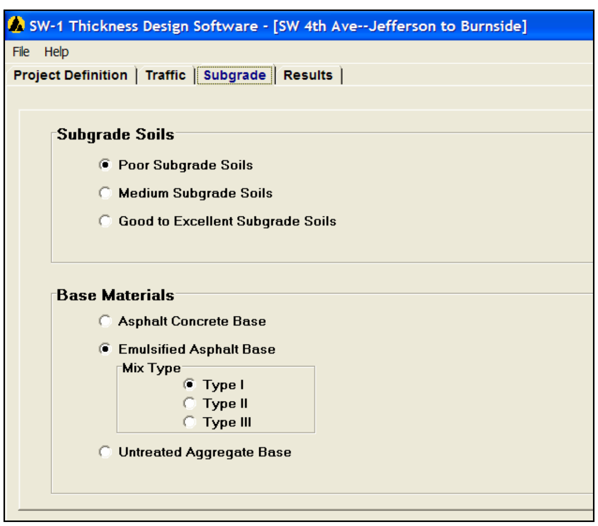
Good to Excellent Subgrade Soils: *Good* subgrade soils retain a substantial amount of their load-supporting capacity when wet. Included are the clean sands and sand-gravels and soils free of detrimental amounts of plastic materials. *Excellent* subgrade soils are unaffected by moisture or frost. They include clean and sharp sands and gravels, particularly those that are well-graded. **Typical properties: M_r = 25,000 psi, CBR = 17, and R-value = 43.**

Base Materials

The simplified procedure includes designs for typical HMA surface and base courses, emulsified asphalt bases, and untreated aggregate bases.

Emulsified Asphalt Mixes: For the emulsified mixes, the user can select from the following mix types:

- **Type I**: Emulsified asphalt mixes made with processed dense-graded aggregates. Plant mixing is required for the high quality, dense-graded Type I mixes in order to obtain the controls necessary for uniform blending of aggregate and emulsified asphalt.
- **Type II:** Emulsified asphalt mixes made with semi-processed, crusher-run, pit-run, or bank-run aggregates. Plant or in-place mixing may be used to produce Type II mixes.
- **Type III:** Emulsified asphalt mixes made with sands or silty sands. Plant or in-place mixing may be used to produce Type III mixes.



Design Process

The design process is to simply select traffic, subgrade, and base material parameters from the available options. For each combination of traffic level, subgrade strength and base material type, SW-1 provides a design section.

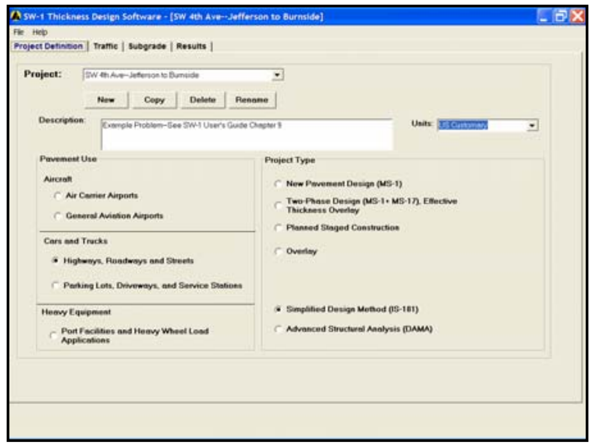
Example Problem—SW 4th Avenue—Jefferson to Burnside

Problem: The City of Portland is planning to reconstruct SW 4th Avenue from Jefferson Street to Burnside Street. Traffic volume on this minor urban arterial is moderate, with approximately 1,000,000 ESALs expected over a 20-year design period. The subgrade soils are native silts and silty clays that become soft when wet. The city transportation bureau is planning to use a plant-produced Type I emulsified asphalt base. What is the recommended pavement section for reconstruction of this street?

Solution:

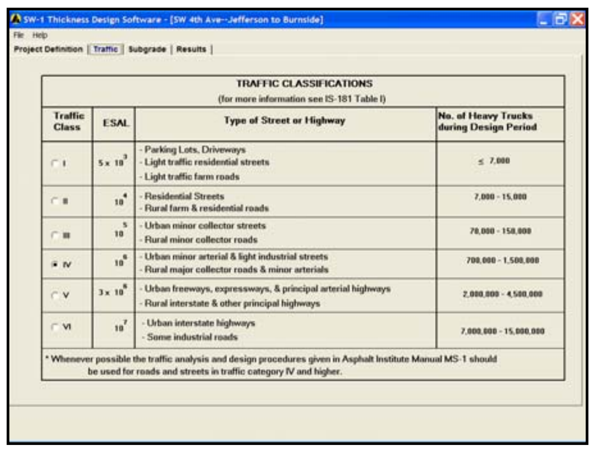
1. Click **New** and create a new project record. Select a **Pavement Use** of Highways, Roadways, and Streets and select Simplified Method (IS-181) as the **Project Type.**

2. Click **Next.**



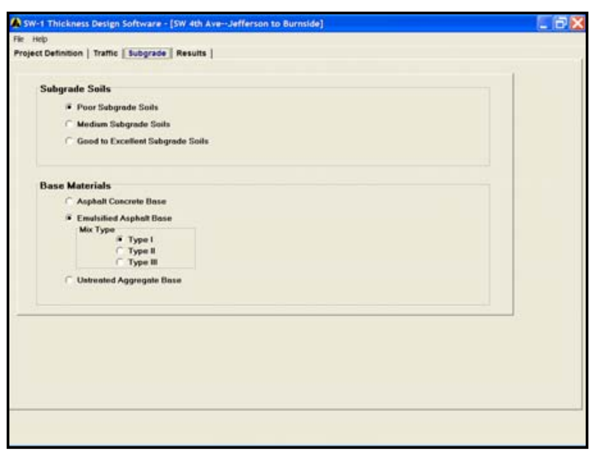
3. On the Traffic Classification screen, select **Traffic Class IV** for and ESAL level 10^6.

4. Click **Next**.

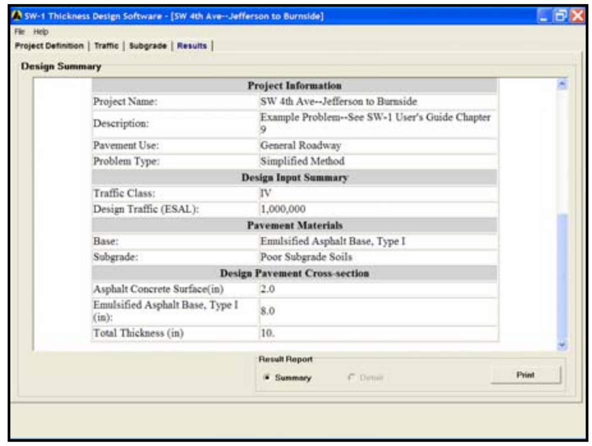


5. On the Subgrade screen, select **Poor Subgrade Soils**. This agrees with the description of silt and silty clay soils that are susceptible to weakening in the presence of water. Also select and **Emulsified Asphalt Base** and **Mix Type I** as the base material type.

6. Click **Next**.



7. On the Results screen, read the **Design Summary** to find that the recommended pavement section is 8 inches of emulsified asphalt base and 2 inches of HMA.



8. Click **Finish** to reveal the screen tabs.

Chapter 10

Planned Staged Construction

Concept

Planned stage construction is the construction of roads and streets by applying successive layers of HMA according to a predetermined time schedule. The design of planned stage construction should not be confused with the design of major maintenance or the rehabilitation of existing pavements. The procedure is based on the presumption that the second stage will be constructed before the first stage shows serious signs of distress.

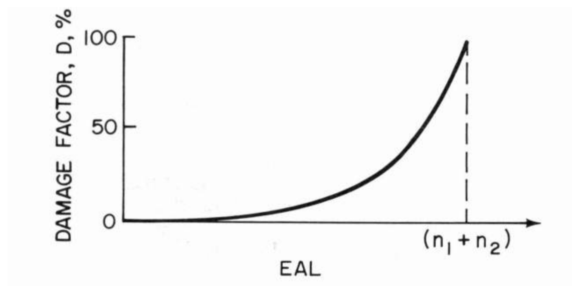


Figure 5—Traditional Design

To illustrate the approach, compare how damage is accumulated in traditional design methods as shown in Figure 5. As traffic is applied to the pavement, damage is accumulated until the damage factor is 100% and the pavement has "failed."

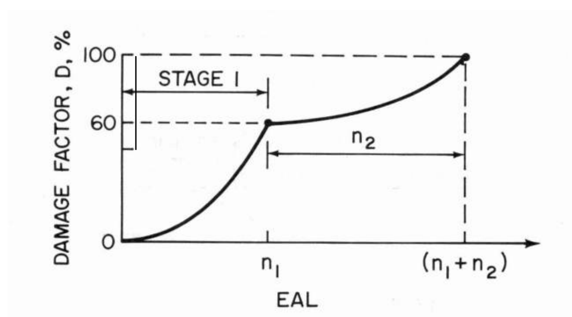


Figure 6—Planned Staged Construction

In Figure 6, the concept of planned staged construction is illustrated. In this method, damage is allowed to accumulate in the first stage up to a damage factor of 60%. At this point the second stage of the pavement section is constructed and damage is allowed to accumulate up to 100%.

Design Inputs

The primary design inputs in the planned staged construction method are the same as those for other Asphalt Institute design methods: traffic

Example Problem—Jasper Street Extension

Problem: The City of Springfield is designing the Jasper Street Extension for planned staged construction. The Stage 1 design period will accumulate 60 percent of total damage within 8 years with Stage 2 accumulating the remaining 40 percent in 12 years. Initial AADT is expected to be 1,800 with 10 percent trucks. Truck classifications are shown in Table 13. Traffic growth is projected at 5 percent annually in this fast-growing rural area. The geotechnical engineer reports the following CBR values: 7, 8, 10, 11, 10, 7, and 9. What is the recommended pavement thickness for Stage 1 and Stage 2 construction?

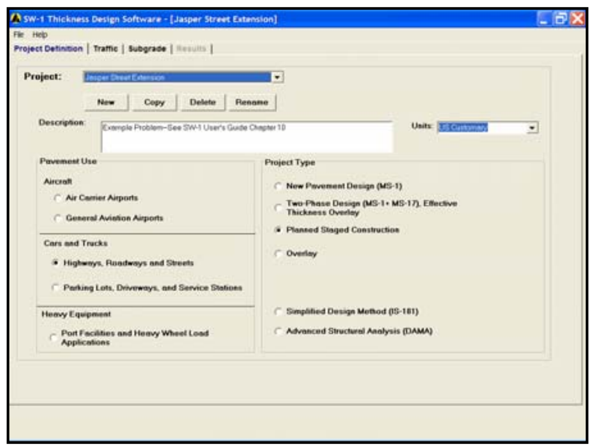
Table 13—Truck Percentages

Truck Type		Percent of Traffic
Single Unit	2-Axle, 4-Tire	70
	2-Axle, 6-Tire	12
	3-Axle or More	2
Multiple Unit	4-Axle or Fewer	0
	5-Axle	16
	6-Axle or More	0

Solution:

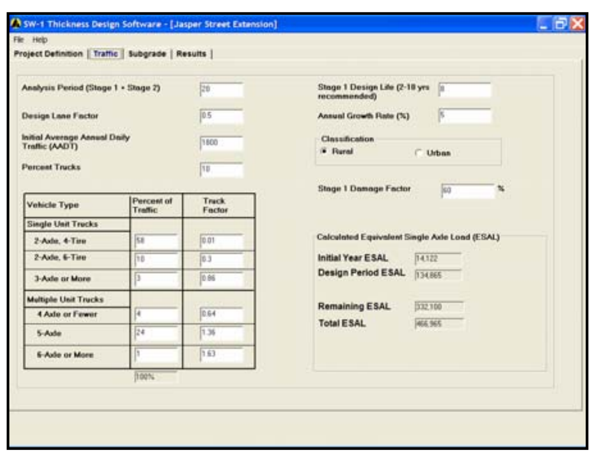
1. Click **New** and create a new project record. Select a **Pavement Use** of Highways, Roadways, and Streets and select Planned Staged Construction as the **Project Type.**

2. Click **Next.**



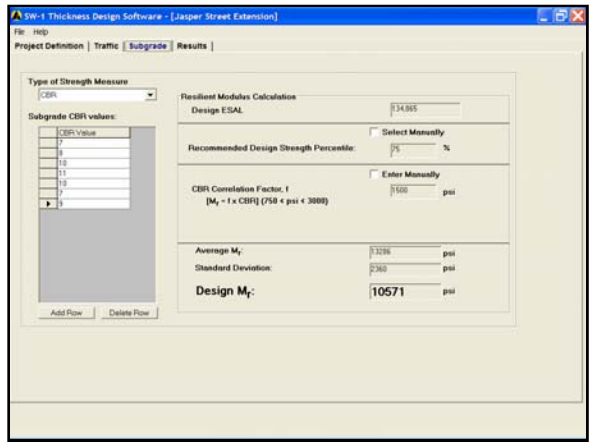
3. On the Traffic screen, enter the data from the Example Problem statement and the truck class percentages from Table 13.

4. Click **Next**.



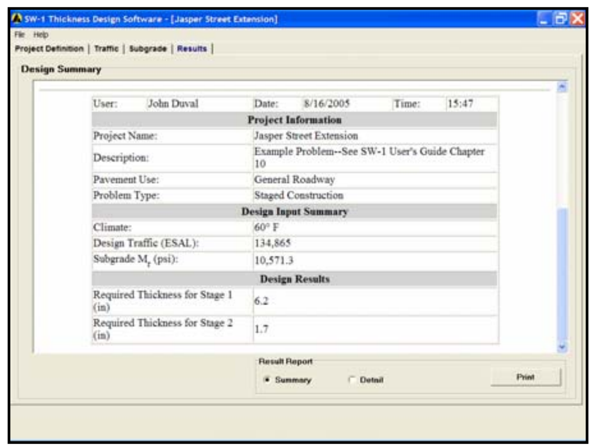
5. On the Subgrade screen, select **Type of Strength Measure** as CBR and enter the CBR values from the problem statement. Note the Design Subgrade Resilient Modulus is 10,571 psi.

6. Click **Next**.



7. On the Results screen select view the **Design Summary** and scroll down to see the Stage 1 and Stage 2 construction thickness is 6.2 inches and 1.7 inches, respectively.

8. Click **Finish** to reveal the screen tabs and perform comparative analyses.

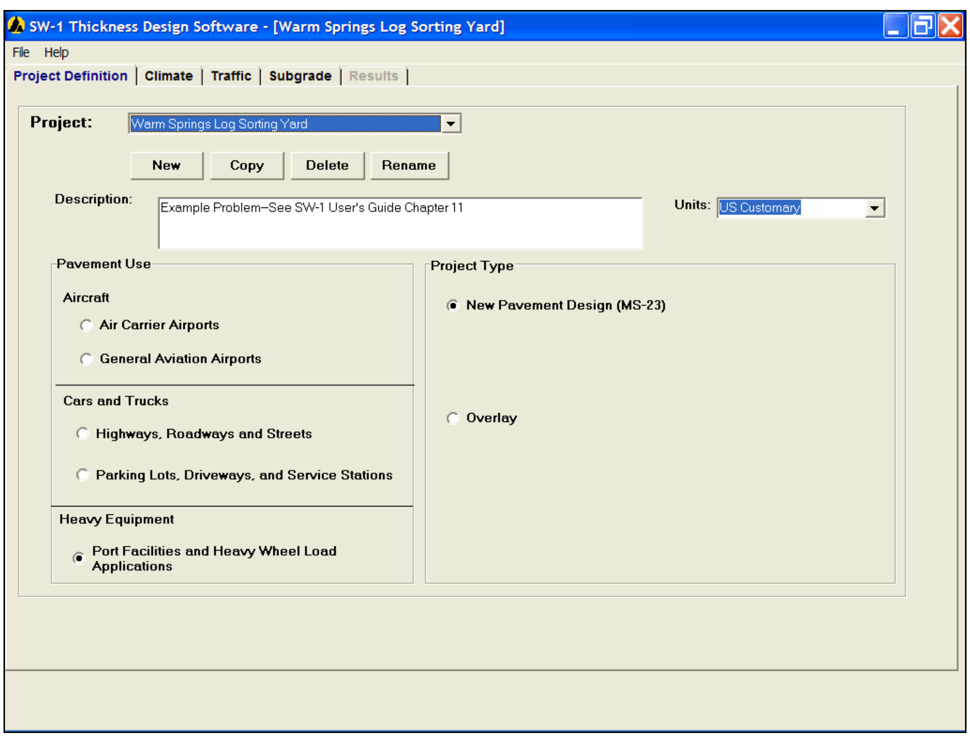


Chapter 11

Heavy Wheel Load Applications

Design of HMA pavements for Port Facilities and Heavy Wheel Load applications is based on the methods detailed in Asphalt Institute Manual MS-23, "Thickness Design—Asphalt Pavements for Heavy Wheel Loads." HMA overlays for heavy wheel applications are designed using methods described in detail in Asphalt Institute Manual MS-17, "Asphalt Overlays for Highway and Street Rehabilitation." This chapter covers new pavement design. For information on overlay design, please see Chapter 9, Overlay Design.

Heavy wheel load vehicles include log-hauling trucks, dump-body haulers, fork-lift trucks, straddle-carriers, rubber-tired hoists, and many special vehicles having as few as four to as many as 12 or more tires. Heavy load vehicles can reach gross vehicle weights in excess of 400 kips.



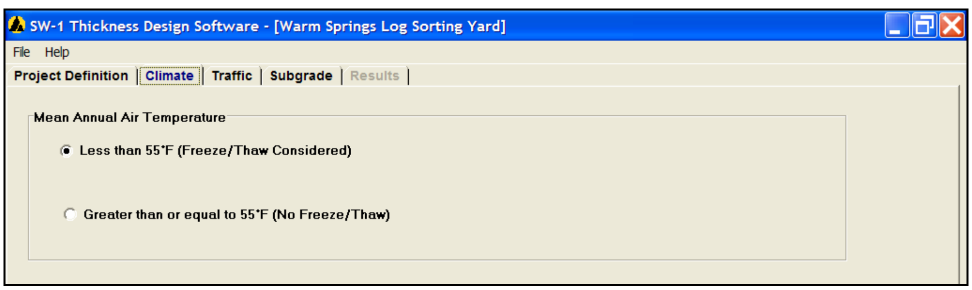
In addition to vehicle and wheel load characteristics, the design thickness of the asphalt pavement will depend on subgrade strength and climate in terms of the mean annual air temperature (MAAT).

Climate

For heavy wheel load applications, only two climate options are available. Both are based on MAAT. Essentially, the choice is between a cold climate where the subgrade is subjected to frost weakening and a warm climate with no freeze/thaw concerns. Table 14 provides descriptions of the climate choices available for heavy wheel load design.

Table 14—Climate Conditions for Heavy Wheel Load Designs

MAAT	Climatic Conditions (30 year averages)	Subgrade Conditions
55ºF or less	Approximately 3 months with average daily temperatures 32°F or below. Yearly average daily temperature of 55°F or less.	Subgrade subject to frost weakening. Gradual increases from a weak spring condition to design modulus in early fall.
Greater than 55ºF	No freezing temperatures. Yearly daily temperature above 55°F.	Subgrade modulus remains reasonably constant, throughout year, at the design value.



Traffic Analysis

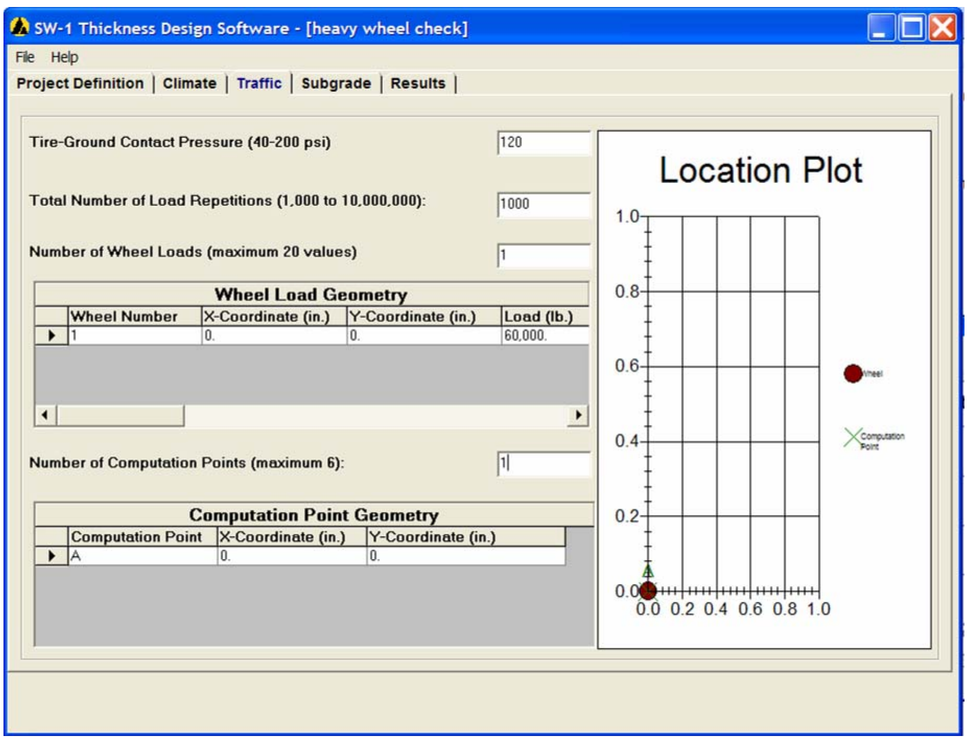
For heavy wheel load applications, the design method in SW-1 treats three general types of problems: single wheel load, dual wheel load, and multiple wheel load problems.

For dual- and multiple-wheel vehicles, SW-1 uses a procedure that is based on the concept that pavement design for multiple wheel vehicles can be accomplished by first calculating an equivalent single wheel load. The equivalent single wheel load is then used to select pavement thickness.

Note: As the name of this section implies, this method is intended for multiple-wheel pavement applications other than highways, roadways, streets, and airports.

Dual and multiple wheel load problems are solved by determining *equivalent* single wheel load. Single wheel load design problems are reasonably simple, requiring only the magnitude of the wheel load (P), the tire-ground contact pressures (p), and the contact area (a), and the number of load repetitions (n). Dual and multiple wheel problems are more complicated, requiring additional wheel geometry data information.

Note: Whether a design problem can be treated as a single wheel depends upon the wheel spacing of the design vehicle. If wheels are separated by a distance greater than eight times the radius of the circular loaded area, the problem may be treated as a single wheel design problem. On the other hand, if the distance between wheels is less than eight times the load radius, the problem should be treated as a multiple wheel problem. **Multiple wheel designs completed using widely spaced wheels (greater than eight times the contact radius) will be overly conservative.**



To set up a single-wheel load problem

1. On the Traffic tab, enter the contact pressure.

2. Enter the number of repetitions expected during the design life of the pavement.

3. In the Number of Wheel Loads box, enter 1.

4. Since only one wheel load is being considered, enter 0 for the X- and Y-Coordinates in the Wheel Load Geometry table. Enter the magnitude of the wheel load under the Load column.

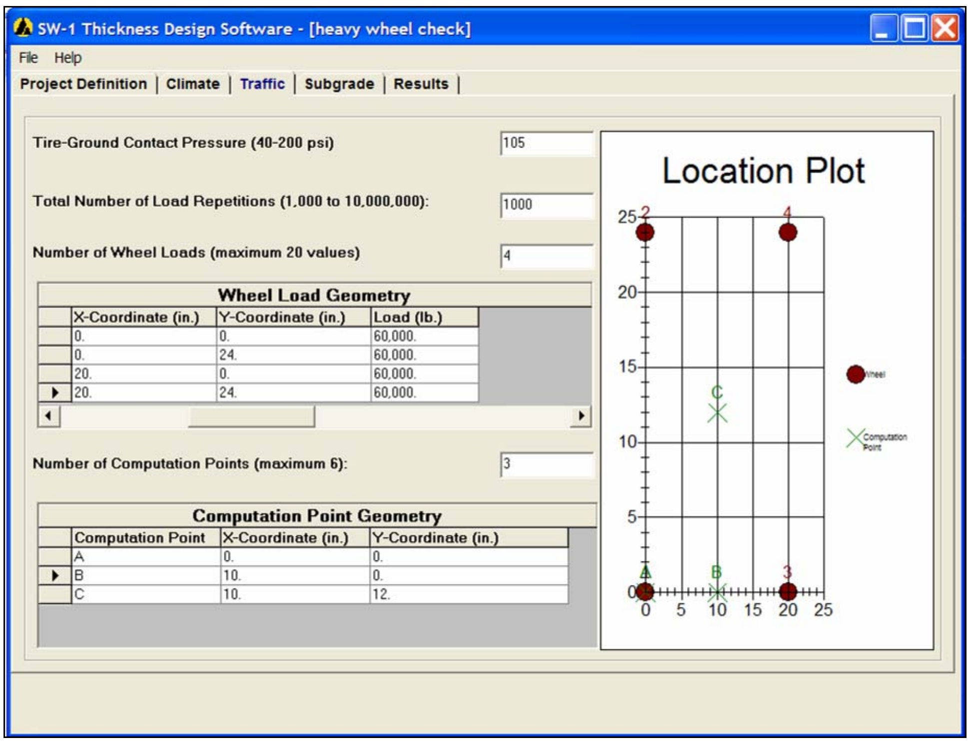
5. Since only one wheel load is being considered, enter 1 in the Number of Computation Points box.

6. For a single wheel problem, enter 0 for the X- and Y-Coordinates in the Computation Point Geometry table.

7. Select **Next** or **Back** or select another tab.

<u>Multiple Wheel Loads</u>

Multiple wheel problems require knowledge of the spacing between wheels and axles. The wheel load geometry establishes the relative locations of the wheels under consideration. The computation point geometry is used to layout the relative location of the points to evaluate for damage. Normally, the computation points are selected as those that accumulate the maximum amount of damage, although the program can compute damage at any point given the relative geometry. Typically, the computation points are directly under a wheel load, at the midpoint between two dual wheels or two groups of wheels on an axle, and halfway between two axles. See the screenshot below for an example layout showing wheel load and computation point geometry for a multiple wheel problem.



To set up a multiple-wheel load problem

1. On the Traffic tab, enter the contact pressure.

2. Enter the number of repetitions expected during the design life of the pavement.

3. In the Number of Wheel Loads box, enter the number of wheels acting together.

4. Enter the X- and Y-Coordinates in the Wheel Load Geometry table.

5. Enter the magnitude of the wheel load under the Load column.

6. Enter the Number of Computation Points box. In the table establish a label for each computation point, such as A, B, C, etc.

7. Enter the X- and Y-Coordinates in the Computation Point Geometry table.

Note: Computation points can be assigned any position on the grid, but are typically selected as the position where the highest strains are likely to occur. Suggested points are directly under one wheel load, at the midpoint between dual wheels or a group of two wheels, and at the center of a larger group of wheels. See the example problem for further detail.

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8. Select **Next** or **Back** or select another tab.

Subgrade

The method for heavy wheel loads uses the standard inputs for subgrade stiffness as described in Subgrade on p. 33.

Results

Once the climate, traffic, and subgrade inputs have been completed, you simply have to click **Next** to get to the Results tab. Please see the section entitled "Viewing Results" on page 25 for more information on viewing and printing the results of your Heavy Wheel Load design.

Example Problem—Warm Springs Log Sorting Yard

Problem: The Warm Springs Forest Products Company is planning to expand their log sorting yard due to an increased volume of business. The primary type of vehicle to be used on the yard is a wheeled loader with a grapple attachment for moving and sorting logs. This vehicle has a gross weight of 110,600 lbs on four wheels with a tire pressure of 65 psi. The wheel load and computation point geometry is shown in Figure 7. Load repetitions are expected to average 15 per hour for each of two 8 hour shifts per day. Assume 260 work days per year.

Subgrade resilient modulus testing has been accomplished and the following values reported: 21,000, 19,500, 18,700, and 19,400 psi. What is the recommended pavement thickness using a 20-year design life?

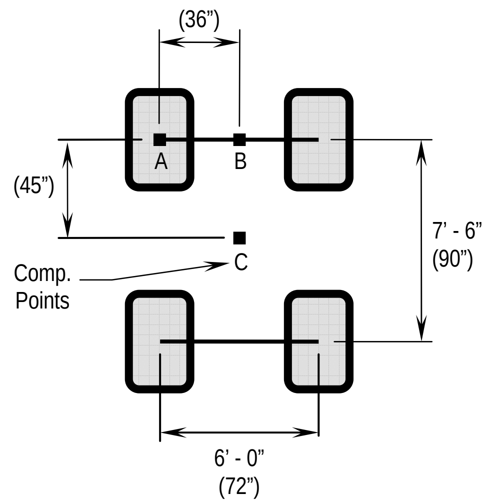
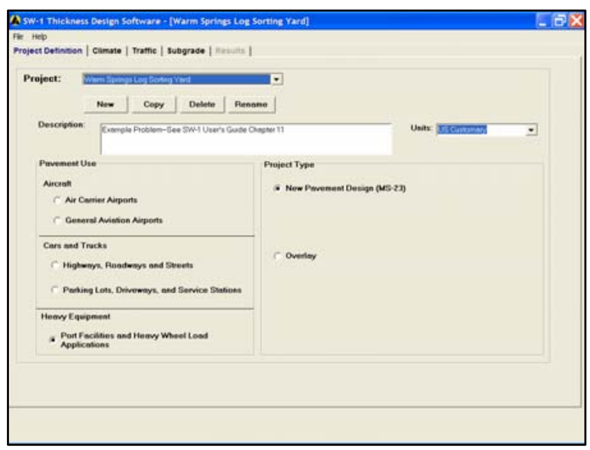


Figure 7—Wheel Load Geometry for Heavy Wheeled Loader

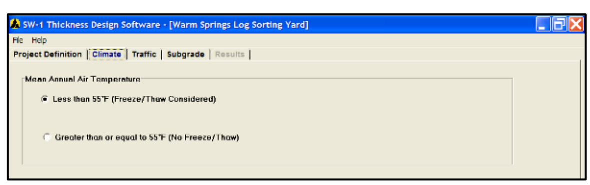
Solution:

1. Click **New** and create a new project record. Select a **Pavement Use** of Highways, Roadways, and Streets and select Planned Staged Construction as the **Project Type.**



2. Click **Next.**

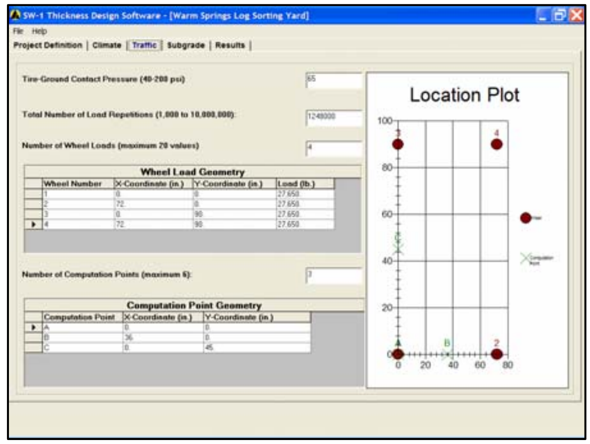
3. On the Climate screen, select the radial button for **MAAT** less than 55ºF (Freeze/Thaw Considered)



4. Click **Next**.

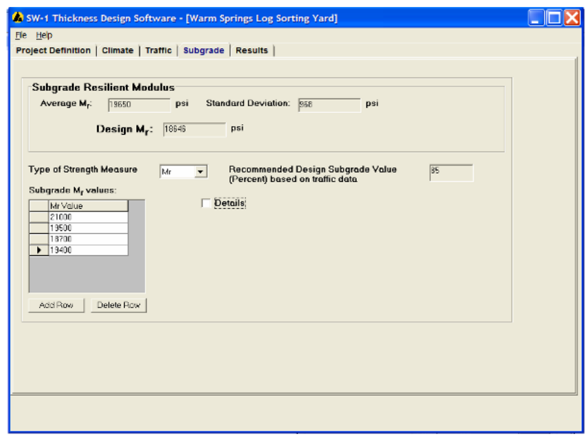
5. On the Traffic screen, enter the data from the Example Problem statement including the wheel load geometry and load information. Note the number of repetitions is calculated to be 1,248,000.

6. Click **Next**.



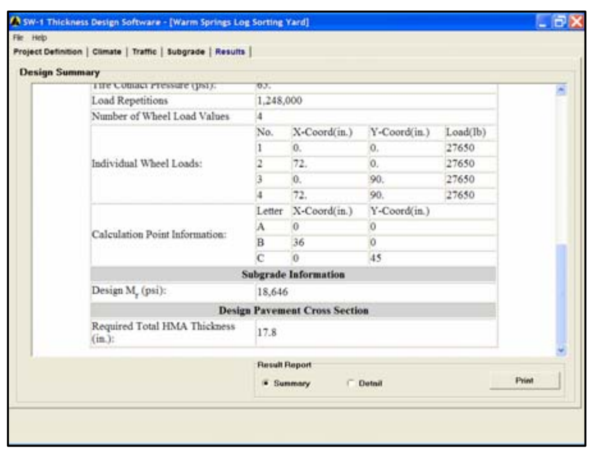
7. On the Subgrade screen, select **Type of Strength Measure** as CBR and enter the CBR values from the problem statement. Note the calculated design M_r is 18,646 psi using a design subgrade value of 85 percent.

8. Click **Next**.



9. On the Results screen select view the **Design Summary** and scroll down to see the recommended design thickness is 17.8 inches.

10. Click **Finish** to reveal the screen tabs and perform comparative analyses.

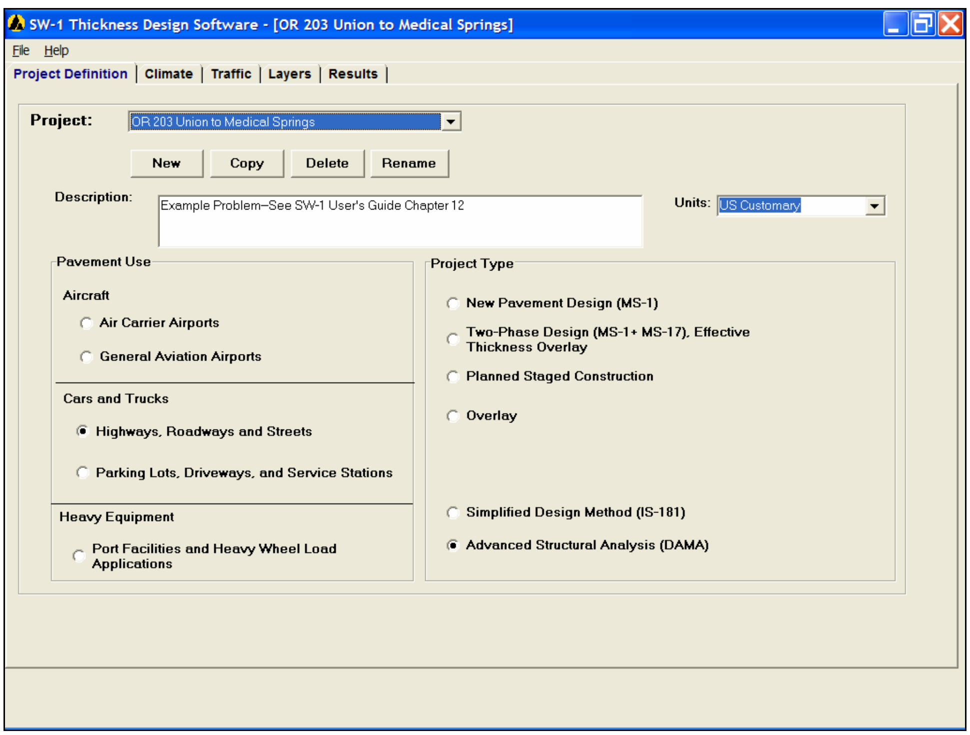


Chapter 12

Advanced Structural Analysis

General Description

SW-1 incorporates the DAMA module for advanced analysis of pavement structures. DAMA was developed as a separate computer program by Dr. Matthew Witczak at the University of Maryland to provide computational basis for developing the structural design curves used in MS-1.

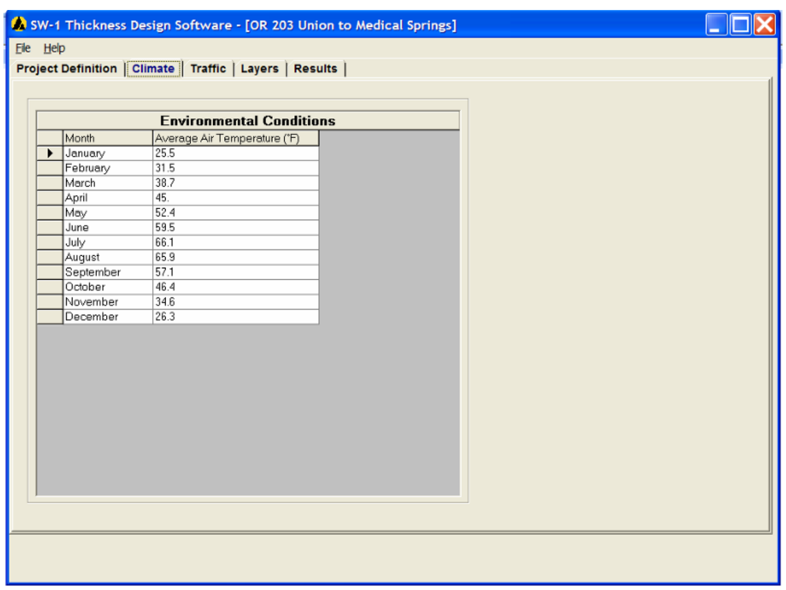


DAMA is used to analyze a multi-layered elastic pavement structure by cumulative damage techniques for a single or dual wheel load system. It can be used for design purposes by analyzing several proposed structures. Many pavement structures comprised of hot-mix asphalt (HMA), emulsified asphalt mixtures, untreated aggregate materials, and subgrade soils can be analyzed provided the maximum number of layers does not exceed five. The program can be used for highway-type loads and for aircraft or other heavy-load vehicles.

The Chevron N-Layer program, developed by Chevron Research Corporation, was modified for dual loading conditions and used to obtain the required elastic solutions within the pavement structure. The DAMA program routinely calculates selected deflection and critical strain values at specified computational points along each critical interface. The detailed report option is provided to allow the user to print all the stresses, strains, and deflections at each layer interface. Critical interfaces are defined as an interface where an asphalt stabilized material is above the interface (several may exist in any given problem) or where a subgrade layer lies below the interface. Three transverse computational points are automatically specified within DAMA to fix the response locations. These computational points are at the center of the one tire, at the edge of one tire, and at the midpoint of the dual-wheel system. In so doing, the program automatically calculates the computational points along the tire center-to-center bisector of the dual wheels. For single-wheel load solutions, the dual tires are simply spaced a large distance apart.

Only the maximum strain at a given depth (interface) is used for the damage computations. Pavement life based on fatigue cracking of asphalt stabilized layers and subgrade deformation distress is determined using monthly cumulative damage concepts. Predicted repetitions to failure for each distress mode and critical layer are obtained from distress strain criteria (input variables) and the maximum strain responses. Damage, computed on a monthly basis for a given monthly traffic repetition input value, is accumulated up to a damage value of 1.0 for both distress modes. The design life and number of load repetitions to failure are summarized for cracking and deformation and the governing layer for the situation is noted.

Climate



Environmental effects are characterized as input variables by mean monthly air temperatures (MMAT) and variable monthly material moduli. The air temperature data are used to account for the effect of temperature on moduli of asphalt mixtures. The capability to account for monthly variations in unbound material properties (base, subbase, or subgrade) allows one to assess the effects of freeze-thaw or variable moisture conditions throughout a pavement life analysis having 12 individual periods (usually months).

The user is asked to provide mean average air temperatures for each of the months. The temperatures used in developing MS-1 are as shown in Table 15:

Table 15—Example Mean Monthly Air Temperature Data

Climate (MAAT)	Month											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
New York (45ºF)	14	25	24	27	42	48	61	69	65	55	48	41
S. Carolina (60ºF)	45	38	43	45	56	70	78	81	78	73	58	54
Arizona (75ºF)	55	61	61	73	90	91	92	93	93	86	72	55

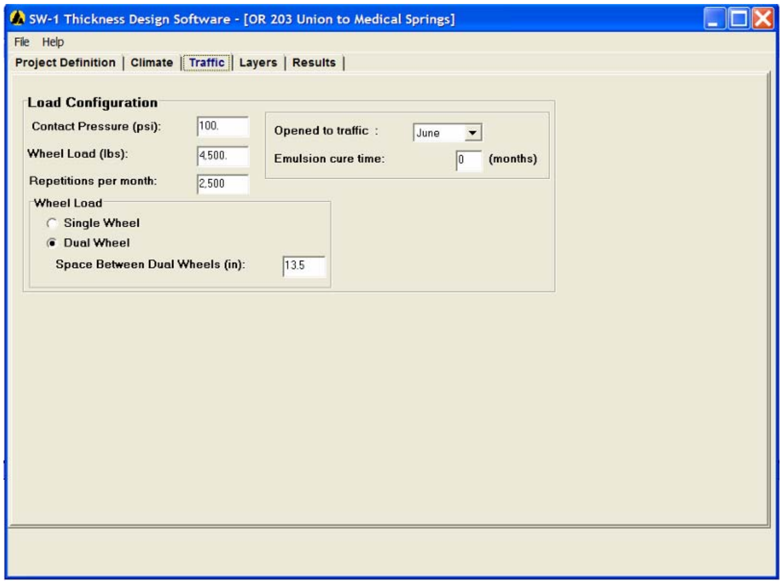
Another source of information is the set of tables in Appendix D of Asphalt Institute MS-17, "Asphalt Overlays for Highway and Street Rehabilitation." These tables, list the normal maximum and minimum temperatures for numerous cities throughout the United States.

Asphalt Emulsion Mixes

For pavements using emulsified asphalt stabilized materials the program will also account for the effects of modulus changes over any specified cure time. Because of the added analytical complexities brought about by this material in the damage computations, damage is computed on a monthly basis for the cure time (in months) plus 12 months for all asphalt stabilized (HMA or asphalt emulsion) problems. For a pavement structure not having an emulsified asphalt layer, the time of cure equals zero and the number of months where damage (structural response) is calculated is 12. The yearly damage for the last 12-month analysis period is then used for all future years until a damage of 1.0 is reached.

Traffic

The basic traffic inputs are shown in figure below. DAMA uses the tire contact pressure, wheel load and space between wheels for duals along with the number of repetitions per month to characterize the load configuration.



To enter Traffic Inputs in the Advanced DAMA Analysis

1. In the Contact Pressure box enter the contact pressure in pounds per square inch. This is the wheel load divided by contact area of tire (can be approximated by inflation pressure).

2. In the Wheel Load box enter the wheel load in pounds. This is one-fourth of the axle load if there are two sets of dual wheels on the axle. Alternatively, this is one-half of axle load if there are only two wheels on the axle.

3. In the Repetitions per Month box enter the number of passes of the above wheel configuration that occur monthly.

4. Select Single Wheel or Dual Wheel axle configuration

5. For dual wheel axle configurations, enter the center-to-center distance between the dual wheels (typically, about 13.5 inches) in the Space Between Dual Wheels box.

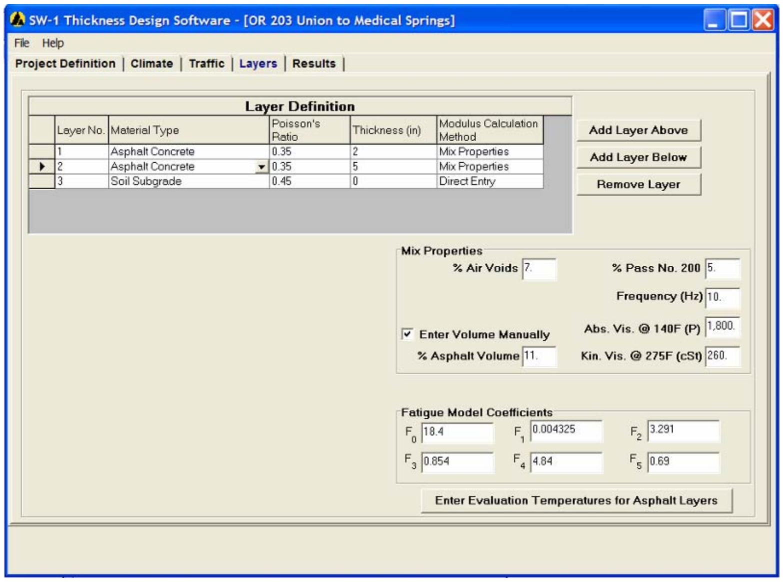
6. Click **Back** or **Next** or select another tab.

Note: These inputs are for typical wheel configurations for highway trucks, but aircraft or other heavy dual or single wheel loads may also be entered here.

Layers

One of the major advantages of the DAMA program lies in its capability to incorporate user-defined material and distress relationships within a monthly damage scheme. Users have the option to input either direct laboratory modulus responses for various design frequencies (load rate) and temperature for a specific mix or to utilize a regression equation developed by the Asphalt Institute. This equation predicts the elastic modulus, E*, which is a function of the percent passing the No. 200 sieve size (P_{200}), asphalt volume (V_b), air voids (V_v), asphalt cement viscosity (η) and mix temperature (T).

On the Layers tab, the user creates the pavement cross-section and supplies pertinent data for each layer. For asphalt concrete layers and aggregate bases, the user has the option of entering the moduli directly or allowing DAMA to calculate the moduli from the mix parameters or a stress-dependent equation, respectively. The moduli of asphalt emulsified base and subgrade layers must be entered directly.



To add a layer to the pavement structure

1. Place the cursor in one of the existing pavement layers above or below the desired location of the new layer.

2. Choose **Add Layer Above** or **Add Layer Below** depending on the position of the cursor relative to the desired location of the new layer.

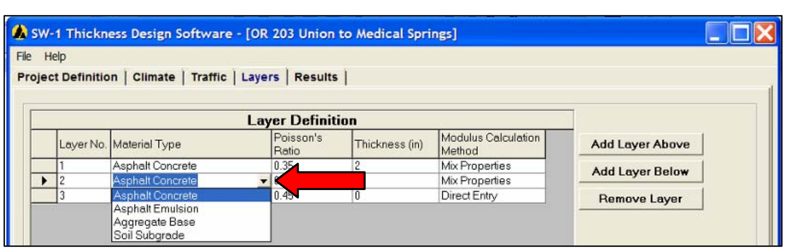
To remove a layer from the pavement structure

1. Place the cursor in the existing pavement layer to be removed.

2. Choose **Remove Layer**.

To change the material type of a layer in the pavement structure

1. Select the target layer by placing the cursor in the existing pavement layer to be modified in the Material Type column. A drop-down arrow should appear on the right side of the Material Type column on the target row.



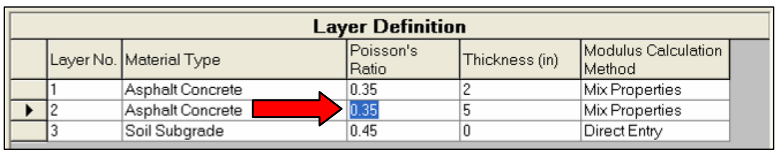
2. Click on the **drop-down arrow** to reveal a list of material types.

3. Select the desire material type from the drop-down list.

Note: There are some limitations in the DAMA module that should be kept in mind. The number of layers is limited to five. The top layer must be asphalt concrete and the bottom layer must be subgrade. Only one aggregate base layer is allowed and it must be directly above subgrade layer.

To change the Poisson's Ratio or layer thickness

1. Select the target layer by placing the cursor in the existing pavement layer to be modified in the Poisson's Ratio or Thickness columns.



Layer Definition				
Layer No.	Material Type	Poisson's Ratio	Thickness (in)	Modulus Calculation Method
1	Asphalt Concrete	0.35	2	Mix Properties
2	Asphalt Concrete	0.35	5	Mix Properties
3	Soil Subgrade	0.45	0	Direct Entry

2. Enter the Poisson's ratio or Thickness directly on the table.

Note: You are not required to enter a thickness value in the bottom subgrade layer which is automatically assumed to have semi-infinite thickness by DAMA.

Note: Poisson's ratio is not a critical value within reasonable limits. The suggested values for each layer type as shown in Table 16:

Table 16—Suggested Values for Poisson's Ratio

Material Type	Suggested Poisson's Ratio
Hot-Mix Asphalt	0.35
Asphalt Emulsion Base	0.35
Aggregate Base	0.35
Subgrade	0.45

To modify the mix properties in the HMA layer

1. Place the cursor in the row for an existing HMA pavement layer.

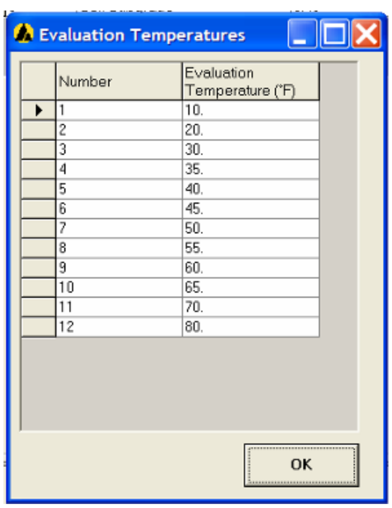
2. Using the mouse or keyboard, position the cursor in the cell of the table containing the variable of interest. Modify the entry and move to the next cell.

The mix properties used in defining the dynamic modulus of hot-mix asphalt and for adjusting the fatigue cracking pavement life equation can be entered on the Layers tab.

Table 17—Mix Property Inputs for Advanced Structural Analysis

Air Voids (V_v)	Must be estimated for both HMA and AE layers (typically 3 to-10 %)
% Asphalt (P_b)	
Asphalt Volume (V_b)	Must be estimated for both HMA and asphalt emulsion layers (typically 9 to 13 % - if left 0, will be calculated from a given P_b)
% Passing #200 Sieve (P_{200})	Needed for HMA layers (typically 2 to 8 %)
Frequency (Hz)	Needed for HMA layers 10 hz ≅ 50 mph 2 hz ≅ 10 mph
Asphalt Binder Viscosity (η)	Needed for HMA layers (will be used to calculate the viscosity at 70°F in poises x 10^6 for the DAMA equation)

In the Layer Material Properties Tab the Evaluation Range of Temperatures is used to establish the monthly modulus-temperature relationship used in the structural analysis and/or design.



Number	Evaluation Temperature (°F)
1	10.
2	20.
3	30.
4	35.
5	40.
6	45.
7	50.
8	55.
9	60.
10	65.
11	70.
12	80.

Results

Strain Values for Damage Analysis

In its original form, the Chevron N-Layer program yields elastic solutions to a single uniform circular load. In order to have DAMA capable of more accurately analyzing a dual wheel load (i.e. 18,000 lb. single axle load), the original Chevron program was modified to analyze computational points at the center of one tire (point 1), the edge of one tire (point 2), and at the midpoint of the dual wheels (point 3). All of these points lie on the center-to-center bisector of the dual wheels.

For vertical subgrade strain (e_v) computations, the individual strains due to each tire (at the point in question) are directly added at any point along the subgrade interface. There is no need in to specify the computational points.

For the principal tensile strain (e_t) computations at the bottom of each asphalt stabilized layer, the sum of tensile strains (radial, tangential and vertical) and the difference of shear strains from the two tires at a given point are obtained to form a strain tensor. Like the vertical subgrade strain analysis, computations are automatically done at each critical interface at the three radial locations noted.

Damage Computations

Subgrade Deformation Damage

In DAMA, one of the two types of pavement distress considered is that of excessive subgrade deformation leading to surface rutting. The criterion used to predict repetitions to failure (N_f) for this mode of distress is based on the magnitude of the vertical compressive subgrade strain (e_v) using:

$N_f = d_O \times (e_v)^{-d_1}$ where: d_O and d_1 are empirical coefficients.

Currently, there are several different types of vertical subgrade strain criteria in the literature. In order to allow DAMA to be as widely applicable as possible, the values of d_O and d_1 are treated as input variables. As a result, DAMA can accept any subgrade criteria of the form shown by the equation. The subgrade strain criterion described by Santucci (1977 International Conference on Structural Design of Asphalt Pavements) was used to develop design charts for MS-1. That relationship used these constants:

$d_O = 0.1365 \times 10^{-8}$

$d_1 = 4.477$

Fatigue Cracking Damage

The other major form of distress analyzed by DAMA relates to fatigue cracking of the asphalt-stabilized layer. Like subgrade deformation distress leading to rutting, several pavement fatigue life criteria are available in the literature. In order to have DAMA as flexible as possible, a special form of the fatigue equations for asphalt stabilized materials was developed. It is:

$N_f = f_0 \times (10^M) \times (f_1 \times e_t^{-f_2}) \times (E^{-f_3})$ with:

$M = f_4 \times [(V_b/(V_v + V_b) - f_s]$

This failure equation should be viewed as having three distinct components:

1. Laboratory to field performance adjustment factor.

2. Mix adjustment factor.

3. Laboratory fatigue equation.

The factor f_o is the "laboratory-to-field performance factor" and represents the numeric value of the "shift" required to relate crack initiation to a "failure condition" of the pavement due to cracking.

The mix adjustment factor, 10^M, is primarily used to adjust the fatigue life predictions due to deviations in mix air voids, V_v, and volume of asphalt, V_b, from those used to establish the laboratory fatigue curves.

The final component, $(f_1 \times e_t^{-f_2}) \times (E^{-f_3})$, represents the laboratory fatigue curve. In this portion, the form of the equation is such that a set of parallel multi-stiffness (asphalt modulus) curves are obtained.

Example Problem—OR 203—Union to Medical Springs

Problem: The Oregon DOT is designing a new pavement section for a particularly challenging section of highway. Due to the high mountain elevations, cool winter temperatures, and freeze-thaw action that take place, the SW-1 advanced structural analysis procedure will be used to analyze one particular design scenario. Traffic volume is 2,500 trucks per month. ODOT uses 13.5 inch dual tire spacing, 4,500 lb wheel load, and 100 psi contact pressure to characterize the design truck wheel load. The design section is full-depth asphalt, with a 2 inch thick wearing course and a 4 inch thick base layer over soil subgrade. Anticipated HMA mix properties for the wearing course are V_a = 4.0%, V_b = 11.0%, P_{200} = 5.0%, Freq = 10 Hz., VIS(140F) = 1,800 Poises, and VIS(275F) = 260 cSt. Anticipated mix properties for the base layer are the same, except that the air voids are expected to be higher, V_a = 7.0%. HMA stiffness is to be estimated by SW-1 using the HMA mix properties evaluated at the following evaluation temperatures in degrees Fahrenheit: 10, 20, 30, 35, 40, 45, 50, 55, 60, 65, 70, 80. Average monthly air temperatures and subgrade resilient modulus values for the past 12 months and are shown in Table 18. What is the anticipated life expectancy of this design scenario? How does the life expectancy change if the base layer is increased to 5 inches thick?

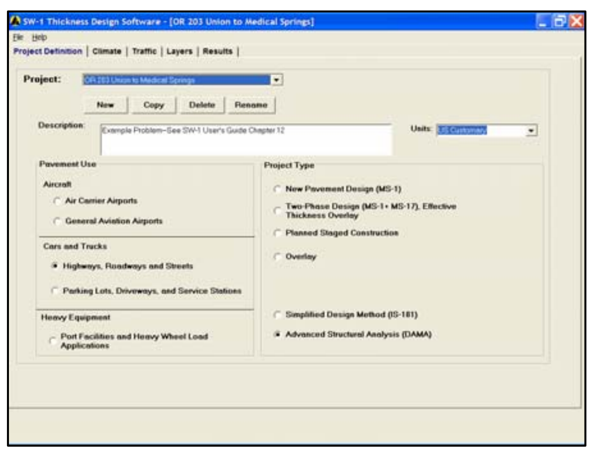
Table 18—Temperature and Subgrade M_r

Month	Temp (ºF)	M_r (psi)
January	25.5	35,600
February	31.5	42,000
March	38.7	29,700
April	45.0	1,800
May	52.4	3,200
June	59.5	4,600
July	66.1	7,500
August	65.9	7,560
September	57.1	7,500
October	46.4	7,500
November	34.6	7,500
December	26.3	14,500

Solution:

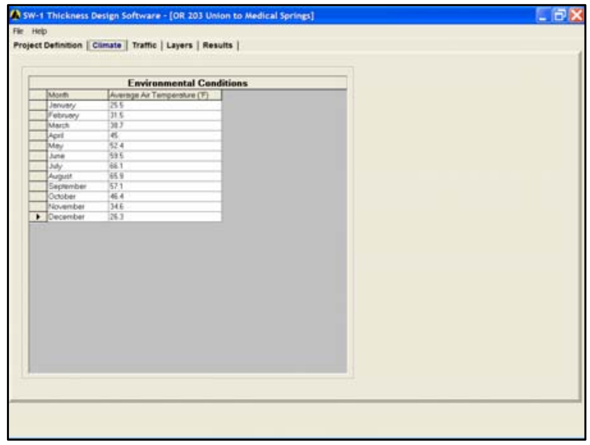
1. Click **New** and create a new project record. Select a **Pavement Use** of Highways, Roadways, and Streets and select Advanced DAMA Analysis as the **Project Type.**

2. Click **Next.**



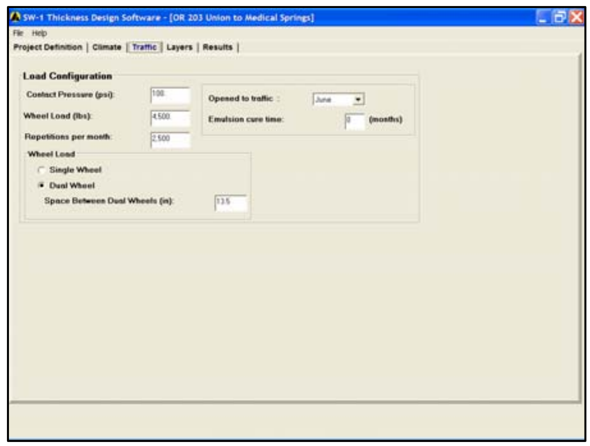
3. On the Climate screen, enter the mean monthly air temperature for each month of the year from the information provided in Table 18—Temperature and Subgrade MrTable 18.

4. Click **Next**.



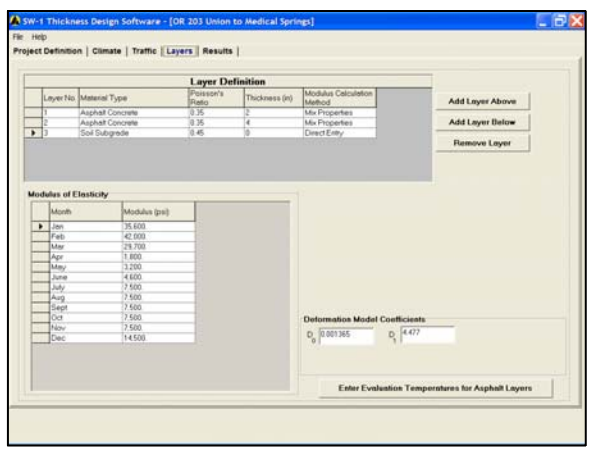
5. On the Traffic screen, enter the data from the Example Problem statement including the tire pressure, wheel load geometry and load repetitions.

6. Click **Next**.



7. On the Layer Definition screen, place your cursor in the grid and establish the layer structure for this problem. Use the **Add Layer Above, Add Layer Below,** and **Remove Layer** buttons as needed and ensure that the appropriate Poisson's Ratio and Thickness is entered. Also, select the appropriate modulus calculation procedure is selected. For this problem, select **Mix Properties** as the calculation method for the HMA layers. For the **Subgrade** layer, select **Direct Entry** as the calculation methodology.

   Note how the screen layout changes as changes are made to the calculation method. Enter the appropriate data in the Layers screen to complete the problem set up.



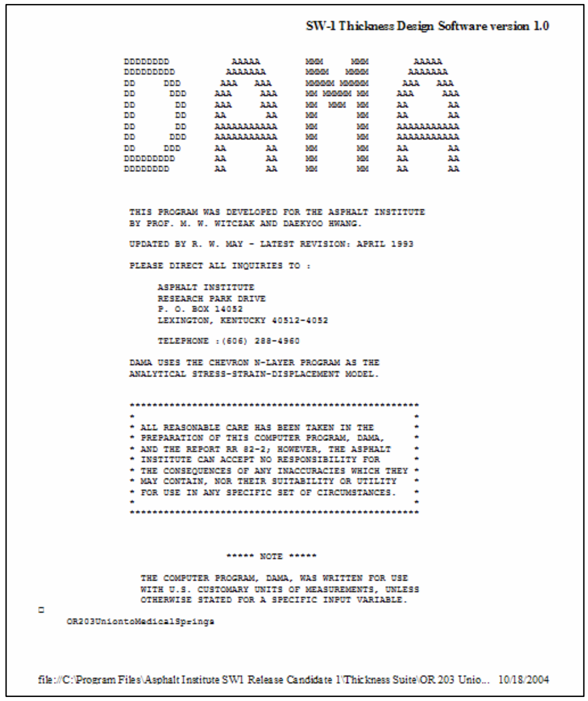
8. Click **Next**.

9. On the Results screen scroll up or down to view the **Design Summary**. Select **Detail** to view the detailed version of the report including stress/strain conditions at the calculation points. Use the **Print** option to view a preview of the complete report.

   By scrolling down to the bottom of the report, view the last section of the report printout, the Design Life Summary. **For the first design section of 2 inches wearing course over a 4 inch base course, note that the design life is estimated to be 24.5 years, based on fatigue failure in Layer 2**.

10. Click **Finish** to reveal the screen tabs. Now, select the Layers tab and change the base layer thickness to 5 inches.

    Return to the Results tab and scroll to the bottom of the report. **For this second analysis, note that the estimated life is more than doubled to 50.7 years, based on fatigue failure in Layer 2.**



SW-1 Thickness Design Software version 1.0

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DDDDDDDD          AAAAA        MMM     MMM        AAAAA
DDDDDDDDD        AAAAAAA       MMMM   MMMM       AAAAAAA
DD     DDD      AAA   AAA      MMMMM MMMMM      AAA   AAA
DD      DDD    AAA     AAA     MM MMMMM MM     AAA     AAA
DD       DD    AAA     AAA     MM  MMM  MM     AA       AA
DD       DD    AA       AA     MM       MM     AA       AA
DD       DD    AAAAAAAAAAA     MM       MM     AAAAAAAAAAA
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DD     DDD     AA       AA     MM       MM     AA       AA
DDDDDDDDD      AA       AA     MM       MM     AA       AA
DDDDDDDD       AA       AA     MM       MM     AA       AA
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THIS PROGRAM WAS DEVELOPED FOR THE ASPHALT INSTITUTE
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UPDATED BY R. W. MAY - LATEST REVISION: APRIL 1993

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DAMA USES THE CHEVRON N-LAYER PROGRAM AS THE
ANALYTICAL STRESS-STRAIN-DISPLACEMENT MODEL.

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**************************************************
*                                                *
* ALL REASONABLE CARE HAS BEEN TAKEN IN THE      *
* PREPARATION OF THIS COMPUTER PROGRAM, DAMA,    *
* AND THE REPORT RR 82-2; HOWEVER, THE ASPHALT   *
* INSTITUTE CAN ACCEPT NO RESPONSIBILITY FOR     *
* THE CONSEQUENCES OF ANY INACCURACIES WHICH THEY *
* MAY CONTAIN, NOR THEIR SUITABILITY OR UTILITY  *
* FOR USE IN ANY SPECIFIC SET OF CIRCUMSTANCES.  *
*                                                *
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***** NOTE *****

THE COMPUTER PROGRAM, DAMA, WAS WRITTEN FOR USE
WITH U.S. CUSTOMARY UNITS OF MEASUREMENTS, UNLESS
OTHERWISE STATED FOR A SPECIFIC INPUT VARIABLE.

OR203UniontoMedicalSprings

file://C:\Program Files\Asphalt Institute SW1 Release Candidate 1\Thickness Suite\OR 203 Unio... 10/18/2004

Glossary

absolute viscosity a measure of the viscosity of asphalt with respect to time, measured in poises, conducted at 60°C (140°F). The test method utilizes a partial vacuum to induce flow in the viscometer.

aggregate a hard inert mineral material, such as gravel, crushed rock, slag, or crushed stone, used in pavement applications either by itself or for mixing with asphalt.

air carrier an aircraft that is used in scheduled and nonscheduled commercial passenger and air cargo service.

air voids internal spaces in a compacted mix surrounded by asphalt-coated particles, expressed as a percentage by volume of the total compacted mix.

aircraft movement one passage of a single aircraft at the critical design location.

aircraft operation an aircraft arrival at or departure from an airport.

analysis period the period of time used in making economic comparisons between alternative designs, including initial construction and future overlays. Analysis period should not be confused with design period.

asphalt binder asphalt cement that is classified according to the Standard Specification for Performance Graded Asphalt Binder, AASHTO Designation MP 320. It can be either unmodified or modified asphalt cement, as long as it complies with the specifications.

asphalt a dark brown to black cementitious material in which the predominating constituents is bitumen, which occurs in nature or are obtained in petroleum processing. Asphalt is a constituent in varying proportions of most crude petroleum and used for paving, roofing, industrial and other special purposes.

backcalculation an analytical technique used to determine the equivalent elastic moduli of pavement layers corresponding to the measured load and deflections. In the iterative method, layer moduli are selected and adjusted until the difference between the calculated and measured deflections are within selected tolerances, or the maximum number of iterations has been reached.

base course the layer in the pavement system immediately below the binder and surface courses. It usually consists of crushed stone, although it may consist of crushed slag or other stabilized or unstabilized material.

benkelman beam the Benkelman Beam measures deflection under a static load such as a truck or aircraft. The truck weight is normally 18 kips (80 kN) on a single axle with dual tires. The tip of the beam is placed between the dual tires and as the vehicle moves away, a measurement of the rebound deflection is made.

california bearing ratio (CBR) a test used for evaluating bases, subbases, and subgrade soils for pavement thickness design. It is a relative measure of the shear resistance of a soil (**see *Soils Manual*, MS-10**).

critical aircraft in the SW-1 method for design of asphalt pavements for general aviation aircraft, the critical aircraft is the aircraft in the traffic mix with the highest gross take-off weight.

critical design location the location where the most damage to the pavement is anticipated in airport pavement thickness design.

DAMA the computer program DAMA was developed at the University of Maryland to provide the computational basis for developing the structural design curves used in the Asphalt Institute design manuals. DAMA is an elastic-layered pavement analysis program used to ascertain the repetitions to failure in the deformation and fatigue cracking distress modes of a given pavement structure in a given environment, subjected to any given design load configuration.

data file in SW-1, data files are created using the **File>New** commands and are opened using the **File>Open** from the main menu. SW-1 creates a Microsoft Access file with a .MDB extension. This file may contain numerous project records.

deflection basin the idealized shape of the deformed pavement surface as a result of a cyclic or impact load as depicted from the peak measurements of five or more deflection sensors.

deflection sensor the term that shall be used to refer to the electronic device(s) capable of measuring the vertical movement of the pavement; and, mounted in such a manner as to minimize angular rotation with respect to its measuring plane at the expected movement. Sensor types include seismometers, velocity transducers, and accelerometers.

deflection a load-induced, downward movement of a pavement section.

design ESAL the total number of equivalent 18 kip (80 kN) single-axle load applications (ESAL) expected throughout the design period.

design lane the lane on which the greatest number of equivalent 18 kip (80 kN) single axle loads (ESAL) is expected. This will normally be either lane of a two-lane roadway or the outside lane of a multi-lane highway.

design period the number of years from the initial application of traffic until the first planned major resurfacing or overlay. This term should not be confused with pavement life or analysis period. Adding HMA overlays as required will extend pavement life indefinitely or until geometric considerations (or other factors) make the pavement obsolete.

design subgrade resilient modulus the value of the subgrade resilient modulus (M_R) used for designing the pavement structure. It is a percentile value of the subgrade resilient modulus test data distribution that varies with design ESAL. The term **design subgrade value** is sometimes used.

design thickness the total thickness of the asphalt mixtures and untreated aggregate layers determined as adequate for a given design situation.

dynaflect the Dynaflect is an electromechanical device for measuring dynamic deflection. It is mounted on a two-wheel trailer and is stationary when the measurements are taken. A 1,000 lb (455 kg) peak-to-peak sinusoidal load is applied through two eccentric masses that counter-rotate at a fixed frequency of 8 Hz. The load is applied through two rubber coated steel wheels. The counter-rotating masses produce a sinusoidal pavement deflection which is recorded by velocity transducers.

effective thickness the ratio of the thickness of an existing pavement material compared to the equivalent thickness of a new HMA layer.

ESAL (equivalent single axle loads) the effect on pavement performance of any combination of axle loads of varying magnitude equated to the number of 18 kip (80 kN) single-axle loads that are required to produce an equivalent effect.

falling weight deflectometer A falling weight deflectometer (FWD) is an impulse loading device that measures pavement response due to the impulse load from a free-falling mass falling onto a rubber buffer that is in contact with the pavement surface. Pavement deflections and a deflection basin are measured using a series of accelerometers.

fatigue resistance the ability of an HMA pavement to resist crack initiation caused by repeated flexing.

full-depth asphalt pavement the term FULL-DEPTH (registered by the Asphalt Institute with the U.S. Patent Office) certifies that the pavement is one in which asphalt mixtures are employed for all courses above the subgrade or improved subgrade. A Full-Depth asphalt pavement is placed directly on the prepared subgrade.

functional overlay the primary purpose of a functional overlay is to restore ride quality, improve surface texture, reduce pavement noise, or act as a maintenance application. The structural benefits of a functional overlay are considered secondary to the primary functional purpose of the treatment. A functional overlay is normally a dense-graded HMA mixture in the range of 2 to 4 in. (5 to 10 cm) thick.

general aviation all types of civil aircraft use other than commercial air carriers. This category covers a wide variety of activity including business, commercial, air taxi, agricultural, aerial photography, pipeline patrol, student instruction, and pleasure flying.

heavy structural overlay heavy structural overlays range in thickness from 5 to 16 in. (15 to 40 cm). They have long expected life; however, their longevity relies on proper pavement preparation and quality of construction.

heavy trucks two-axle, six-tire trucks or larger. Pickup, panel and light four-tire trucks are not included. Trucks with heavy-duty, wide-base tires are included.

highway capacity the practical capacity of a street or highway in terms of the maximum number of vehicles of all types for which the highway should be geometrically designed.

hot mix asphalt (HMA) overlay one or more courses of HMA over an existing pavement.

hot mix asphalt (HMA) high quality, thoroughly controlled hot mixture of asphalt binder (cement) and well-graded, high quality aggregate, which can be compacted into a uniform dense mass.

improved subgrade subgrade that has been improved as a working platform by: 1) the incorporation of granular materials or stabilizers such as asphalt, lime, or portland cement into the subgrade soil; 2) any course or courses of select or improved material placed on the subgrade soil below the pavement structure.

kinematic viscosity a measure of the viscosity of asphalt, measured in centistokes, conducted at a temperature of 135°C (275°F).

MAAT **m**ean annual air temperature.

nondestructive testing (NDT) in the context of pavement evaluation, NDT is deflection testing, without destruction to the pavement, to determine a pavement's response to pavement loading.

pascal-seconds the SI unit for viscosity. 1 Pascal-second equals 10 poises.

pass see **aircraft movement**

pavement structure the entire pavement system of selected materials from subgrade to the surface.

performance grade (PG) asphalt binder grade designation used in Superpave. It is based on the binder's mechanical performance at critical temperatures and aging conditions.

planned stage construction a construction process where stages of the project are performed sequentially according to design and a predetermined time schedule.

poise a centimeter-gram-second unit of absolute viscosity equal to the viscosity of a fluid in which a value of stress one dyne per square centimeter is required to maintain a difference of velocity of one centimeter per second between two parallel planes in the fluid that lie in the direction of flow and are separated by a distance of one centimeter.

project record in SW-1 a project record is the record of an individual project or problem that is stored within a SW-1. Many project records can be stored in a single data file. Sample project records come with the SW-1 program and are installed when SW-1 is installed on your computer.

rebound deflection the amount of surface rebound when a load is removed.

representative rebound deflection the mean value of measured rebound deflections in a test section, plus two standard deviations, adjusted for temperature and most critical period of the year for pavement performance.

residual deflection the difference between original and final elevations of the pavement surface resulting from the application to, and removal of, one or more loads from the surface.

resilient modulus of elasticity (M_R) a laboratory measurement of the behavior of pavement materials to characterize their stiffness and resiliency (see *Soils Manual,* MS-10). A confined or unconfined test specimen (core or re-compacted) is repeatedly loaded and unloaded at a prescribed rate. The resilient modulus is a function of load duration, load frequency, and number of loading cycles.

resistance value (R-value) a test for evaluating bases, subbases, and subgrade for pavement thickness design.

road rater the Road Rater measures dynamic deflection using a sinusoidal force generated by a hydraulic acceleration of a steel mass. Models are available with peak-to-peak loading of 1,000 to 8,000 lb. (455 to 3,630 kg). Pavement response is measured at the center of the loading plate and at radial offset distances using up to 7 velocity transducers.

standard aircraft the aircraft used to determine the traffic factor for design purposes in the Asphalt Institute design procedure for air carrier airports. Load repetitions for the mix of aircraft traffic expected at the facility are converted to equivalent strain repetitions of a "standard aircraft" at maximum gross weight of 358,000 lb (1590 kN).

standard deviation the root-mean-square of the deviations about the arithmetic mean of a set of values.

stoke a unit of kinematic viscosity equal to the viscosity of a fluid in poises divided by the density of the fluid in grams per cubic centimeter.

structural overlay structural overlays add strength to the existing pavement and typically ranges in thickness from 4 to 6 in. (10 to 15 cm).

subgrade resilient modulus the modulus of the subgrade determined by repeated load, triaxial compression tests on soil samples. It is the ratio of the amplitude of the accepted axial stress to the amplitude of the resultant recoverable axial strain, generally designated by the symbol M_R.

subgrade the soil prepared to support a pavement structure or a pavement system. It is the foundation of the pavement structure.

truck factor the number of ESALs contributed by one passage of a vehicle. Truck factors can apply to vehicles of a single type or class or to a group of vehicles of different types.

viscosity a measure of a liquid's resistance to flow with respect to time.

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