

Computer-Based Guidelines for Concrete Pavements, HIPERPAV III® Version 3.3 User's Manual

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FOREWORD

The High PERFORMANCE PAVING (HIPERPAV®) software program allows users to predict early-age concrete pavement behavior based on user-defined input for environmental, design, and construction condition. The user input includes variables such as ambient weather conditions, thickness of pavement, mix design, time of placement, and type of curing. Mathematical models then calculate the progression of the concrete's strength gain and developing stresses at the early age after placement. HIPERPAV® was first released in 1996, followed by an updated version in 2005. In 2010, HIPERPAV III®, version 3.2, was released with enhanced moisture transport modeling.

The new version of software, HIPERPAV III®, version 3.3, includes two new features: automated downloading of weather data from the National Weather Service Web site and the addition of slag aggregate input. The new default values for the coefficient of thermal expansion of Portland cement concrete were also incorporated. This manual provides general instruction on the use and application of the software program, which can be very helpful to engineers, contractors, and concrete suppliers. HIPERPAV® can be used during planning, design, construction, and post-construction evaluation phases. Typical applications include optimizing pavement designs and construction methods thereby preventing the need for expensive pavement repairs in the future, developing project quality control specifications to ensure optimized methods are followed, and conducting forensic investigations to identify potential early-age factors that may have led to specific performance patterns after construction.

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Director, Office of Infrastructure
Research and Development

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16. Abstract The Federal Highway Administration's High PERformance PAVing (HIPERPAV®) software program has been upgraded to include the following new features in its latest version, HIPERPAV III®, version 3.3: <ul style="list-style-type: none"> • The coarse aggregate input now includes an option for use of blast furnace slag aggregate. • The user has the ability to download forecasted weather data from the National Oceanic and Atmospheric Administration's National Weather Service Web site and have that data automatically entered as inputs for ambient temperature, relative humidity, wind speed, and cloud coverage. <p>This report serves as the user's manual for the HIPERPAV III®, version 3.3, software. Users can download the software at the following URL: http://www.fhwa.dot.gov/software/research/infrastructure/pavements/hiperpav/ver3-3.</p>			
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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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CHAPTER 1. INTRODUCTION

High Performance PAVing (HIPERPAV®) is a software tool that uses a systems approach for predicting the early-age behavior of jointed plain concrete pavements (JPCP) and continuously reinforced concrete pavements (CRCP). In addition, long-term JPCP behavior can be evaluated based on early-age JPCP analyses.

This kind of a tool can be very helpful to engineers, contractors, and concrete suppliers. HIPERPAV® can be used during planning, design, construction, and post-construction evaluation phases. Typical applications for which it can be useful include optimizing pavement designs and construction methods, thereby preventing the need for expensive pavement repairs in the future; developing project quality control specifications to ensure optimized methods are followed; and conducting forensic investigations to identify potential early-age factors that may have led to specific performance patterns after construction.

There have been several versions of HIPERPAV®, starting with the official first release, HIPERPAV® I (version 2.0). Since its inception, it was always understood that HIPERPAV® would need to evolve as new materials were introduced into the industry, new discoveries in research were reported, and new models for predicting concrete behavior were developed. For this reason, there have been a number of versions of HIPERPAV® developed over the years. Each new version includes new features that address ways to improve analyses and user friendliness. Subsequent versions to 2.0 include HIPERPAV II® (version 3.0), HIPERPAV III® (version 3.2), and now HIPERPAV III® (version 3.3).^(1,2)

This manual is intended to provide guidance on how to use HIPERPAV III® (version 3.3). Listed below are several key features that distinguish HIPERPAV III® (versions 3.2 and 3.3) from HIPERPAV II® (version 3.0) and HIPERPAV I® (version 2.0).

- Enhanced moisture model that improves the accuracy of the software's predictions was incorporated.
- Improved interface, which allows users to navigate the software with more ease.
- Ability to characterize the heat evolution of a particular cement paste, which improves the precision of the software's models.
- Batch mode that allows the user to analyze several strategies at once.
- Comparisons module (also referred to as the Comparisons Tool) that includes sensitivity analysis tools that allow the user to quickly discern differences in the effects of design, materials, construction, and climatic variables on strength gain, stress development, and early-age strength-to-stress relationships.

The latest release of HIPERPAV®, HIPERPAV III®, version 3.3, includes three additional key features to those listed above. The following key features were added in version 3.3:

- Ability to analyze mix designs that include blast furnace slag aggregate.

- Ability to download online forecasted weather data.
- Updated default values for Portland cement concrete (PCC) coefficient of thermal expansion (CTE) in accordance with recent research conducted by the Federal Highway Administration (FHWA), which suggests that default values used in previous versions of HIPERPAV® were overestimated.

In subsequent paragraphs, HIPERPAV III® (version 3.3) is referred to as version 3.3. Likewise, previous versions are referred to simply by their software version number. The following chapters and subsections guide the user through using the software in a step-by-step manner. The chapters are broken down by the type of project (i.e., early-age JPCP, long-term JPCP, or early-life CRCP) that will be analyzed. Subsections within the chapters explain how to navigate each section and corresponding input windows.

GETTING STARTED

Download the software at the following URL:

<http://www.fhwa.dot.gov/software/research/infrastructure/pavements/hiperpav/ver3-3>.

Clicking the icon that appears on the desktop launches the software in any HIPERPAV® version. If there is no icon but the software is installed, click the “Windows_Start” button and select HIPERPAV® from the menu under “All Programs”.

Once the software is launched, the New Project window appears, which prompts the user to choose the type of project for which the analysis (or analyses) will be run. Click the option button next to the appropriate choice. (Figure 1 shows the very first window that appears in all versions of HIPERPAV® with “Early-Age JPCP” selected as the project type.) Then click “OK”. Now the user is ready to enter job-specific inputs for the project type selected.

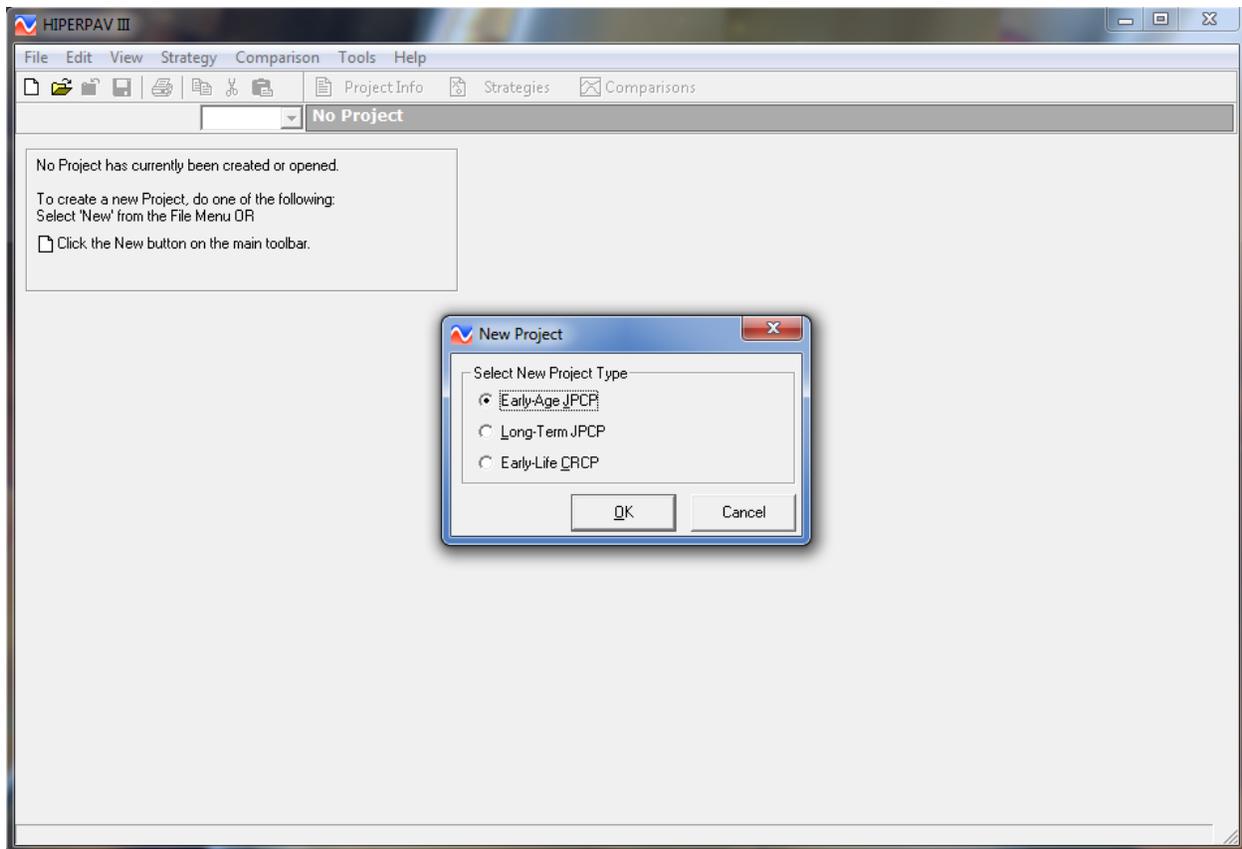


Figure 1. Screen Capture. Opening window showing the New Project selection window with options for type of project to analyze.

Once the user has selected a project type, the user must navigate through a few input windows for each type of project to create a strategy. Strategies are further explained in the Strategies subsection of chapter 2 of this manual. Input windows are grouped in categories within sections. Sections are represented by tabs (Project Info, Strategies, and Comparisons) located horizontally in the main toolbar at the top as shown in figure 2. Input and analysis windows for each section are listed in tree view on the left side bar of every window (see Project Information, Geography, and Monthly Weather Data in figure 2). The first input window for all three project types is the Project Information window under the Project Info tab (see figure 2).

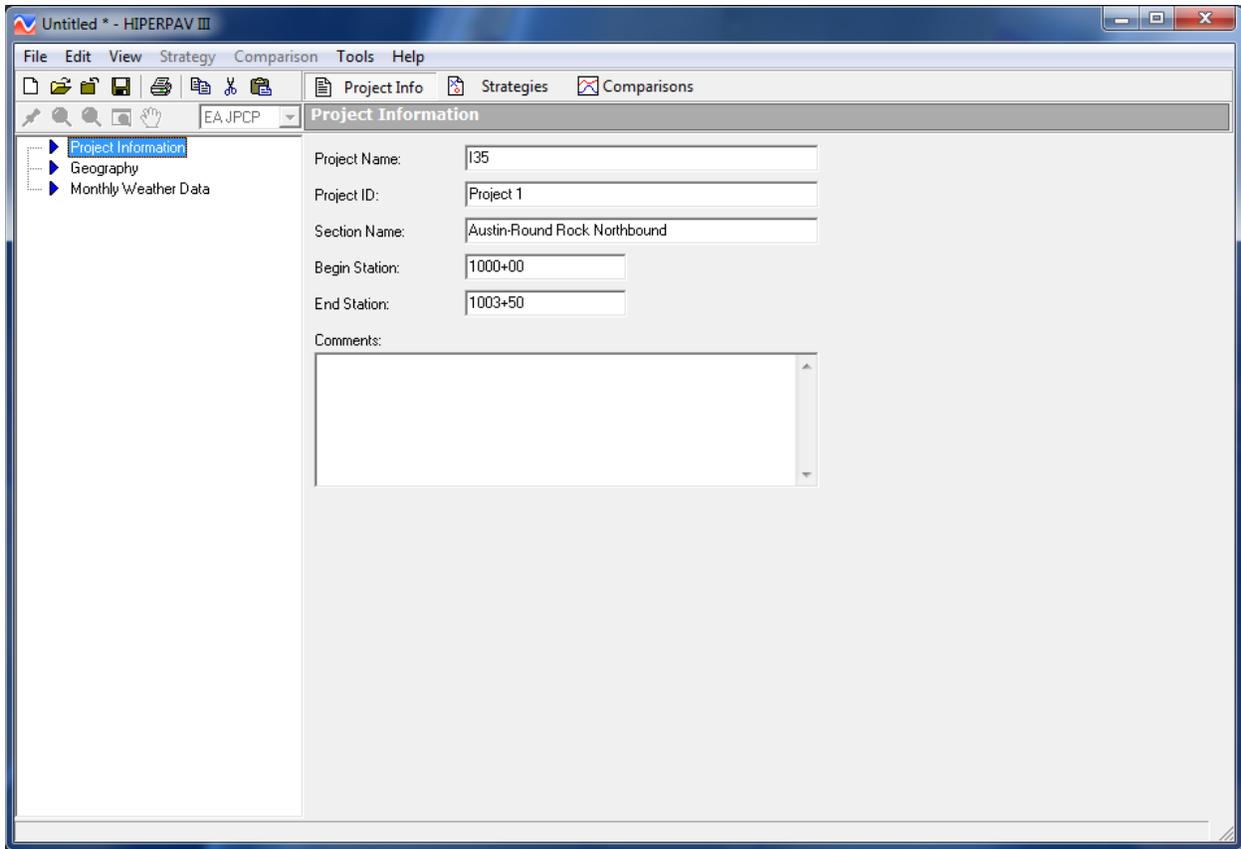


Figure 2. Screen Capture. Project Information input window under the Project Info tab.

CHAPTER 2. EARLY-AGE JPCP PROJECTS

This chapter provides guidance on how to navigate the early-age JPCP project type sections and input/analysis windows. Sections include Project Info, Strategies, and Comparisons tabs.

PROJECT INFO

There are three categories under the Project Info tab: Project Information, Geography, and Monthly Weather Data (see figure 2).

Project Information

The Project Information category consists of only one input window, which appears immediately after choosing early-age JPCP as the project type (figure 2). In this window, the user can enter general project information, including the project name, project ID, section name, and station numbers corresponding to the beginning and end of the project to be analyzed. A comment box is also provided for the user to enter any additional information.

Geography

The Geography category is the second category of input windows listed. It consists of one window with input fields. To navigate the Geography window, five tools with corresponding icons are available for use. The user can click the icons shown in figure 3:



Magnify the map.



Decrease magnification of the map.



Select the location of the project.



Drag the map.



Zoom to show the entire map.

Figure 3. Screen Capture. Icons for navigation tools in the Geography window.

The user should select the location of the project within the 50 States (see, for example, figure 4). This step is important because weather data obtained from historical records or from downloaded forecast data rely on this input. When a project location is selected, the software automatically identifies the nearest weather stations and performs a weighted average of the historical data available for air temperature, wind speed, relative humidity, and cloud cover. The averaged data are automatically entered as the default values in the Climate window. The Climate window is named Environment in versions of HIPERPAV® previous to version 3.3. If the user chooses to download current forecasted data, instead of relying on historical averages, the data retrieved are specific to the location as identified by this input.

To select a location, first click the pushpin icon and then select the location on the map. Once the location has been selected on the map, it is highlighted in yellow. Location latitude, longitude, and elevation automatically appear in the box on the right above the map. Alternatively, latitude and longitude can be entered manually, and the location is selected by clicking “Set Location” (elevation does not need to be entered). In the box above the map and to the left of the location information, the cities with weather stations nearest that location are indicated in bolded font.

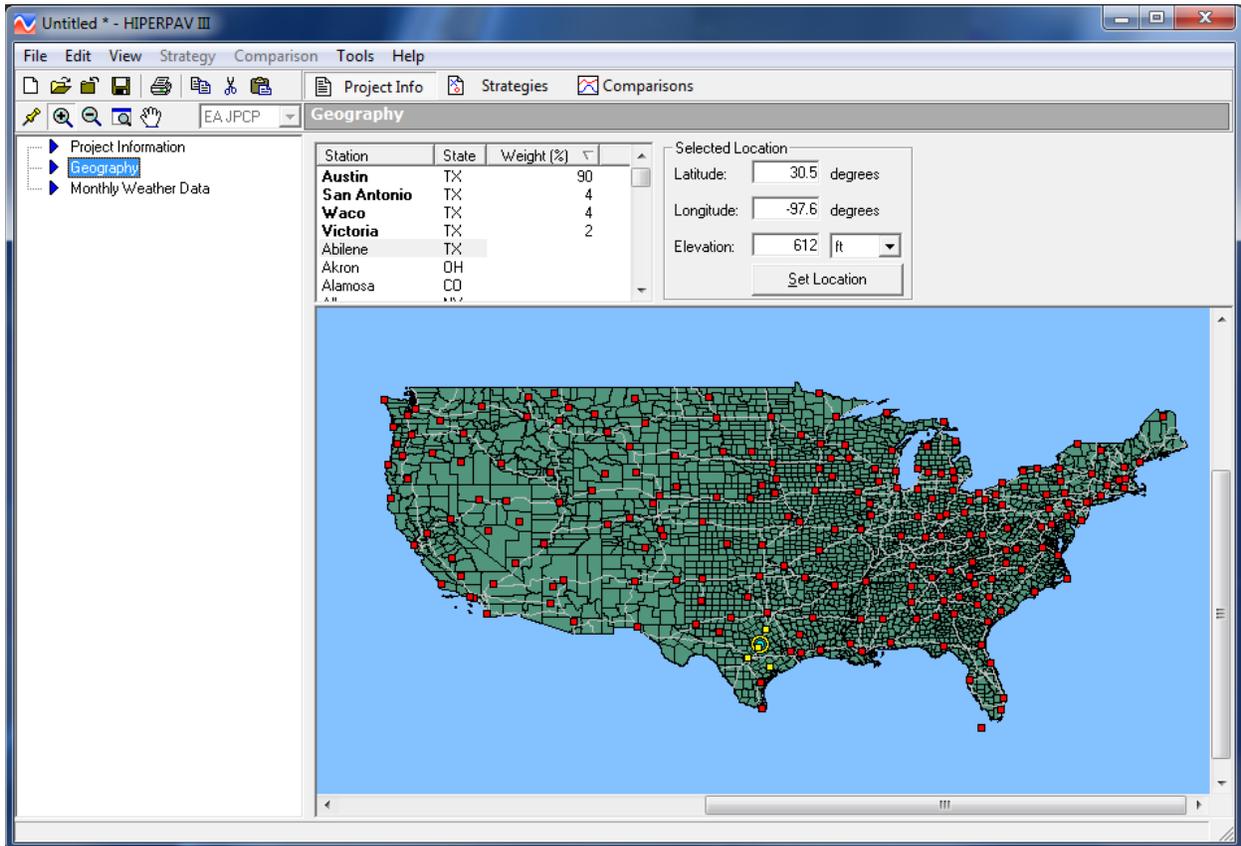


Figure 4. Screen Capture. Geography window showing a yellow circle around a yellow point to indicate project location and additional yellow points indicating the nearest weather stations (Austin, TX).

Monthly Weather Data Window

If the user has more accurate rainfall data, those data can be entered in the input window for Monthly Weather Data (figure 5). This window appears for early-age and long-term JPCP project types, but does not appear for CRCP projects. It should be noted that monthly rainfall data are used for the long-term JPCP analysis only.

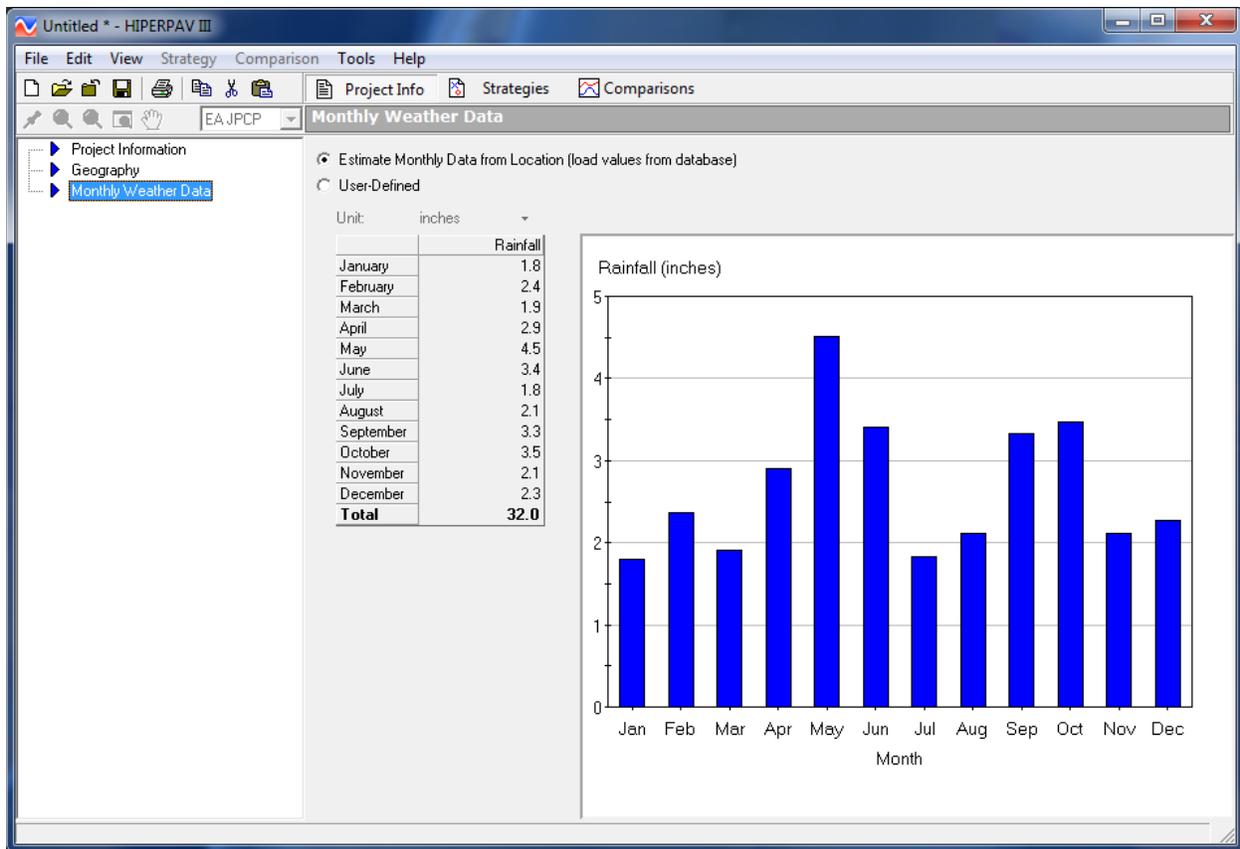


Figure 5. Screen Capture. Inputs to the Monthly Weather window.

STRATEGIES

After navigating through the windows in the Project Info tab, the next step is to navigate the windows in the Strategies tab. Individual strategies for a single combination of structural design, materials and mix design, construction methods, and climate inputs are created under this tab. Initially, a single default strategy is created based entirely on inputs entered thus far under the Project Info tab and default values automatically entered into input fields within the input windows under this tab. The default values represent typical inputs for a paving project. Creation of this initial strategy and the ability to add additional strategies are accomplished by using the strategy toolbar and then navigating through a number of input windows.

Over the years, following the release of version 2.0, features were added to the software making it more user friendly. These features include help icons and the option to use a simplified set of input windows under the Strategies tab. Help icons were added to version 3.0 and appear next to selected inputs on various windows in the Strategy section. These icons link the user to more information about that specific input. In addition to the help icons, in version 3.2, two use levels were incorporated: a Simple View, which is intended for novice users and users with very limited project-specific information, and an Advanced View, which is intended for users with more experience in pavement design and who have more detailed data that can be used as inputs (see figure 6). The user can choose which view is preferred by clicking View in the main toolbar

(see figure 7) and scrolling down to select the right choice from the drop-down menu. Note that the Simple View is an option only for early-age JPCP projects.

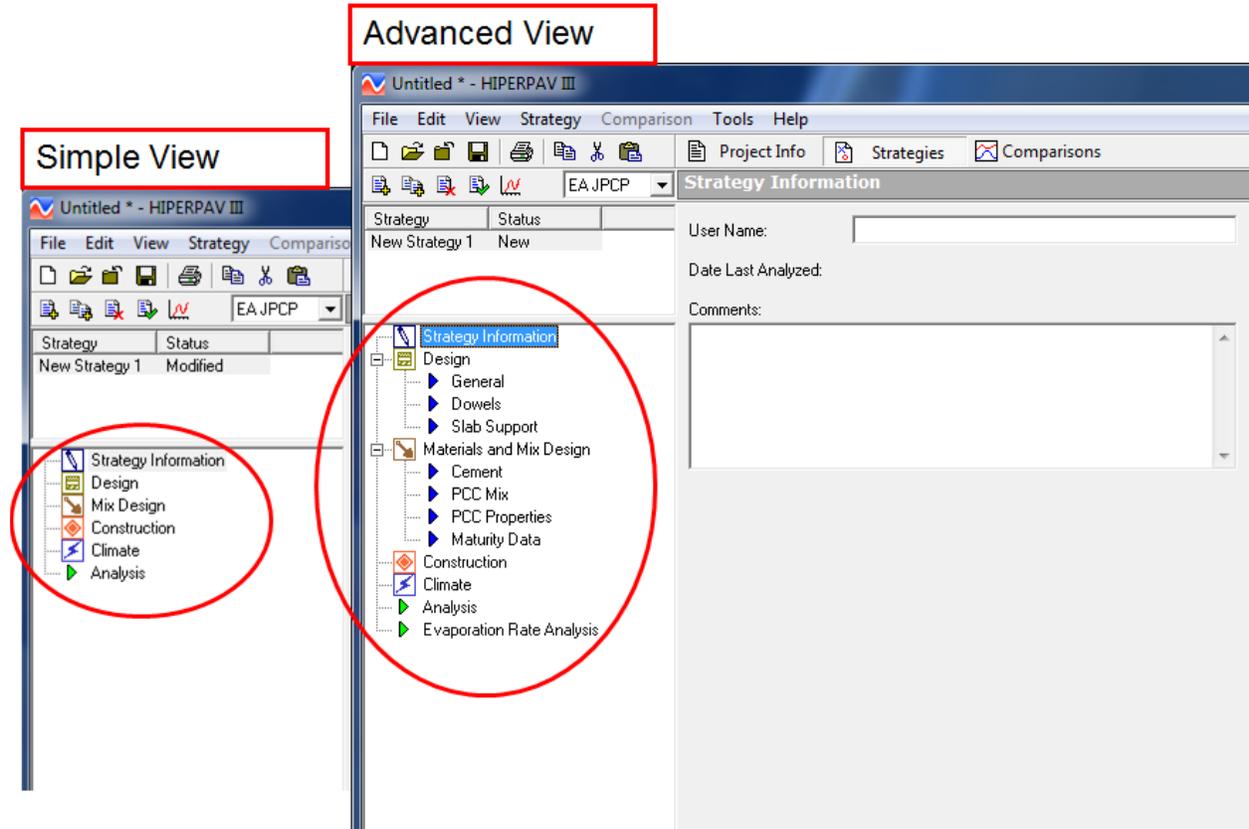


Figure 6. Screen Capture. Comparison of Simple and Advanced Views.

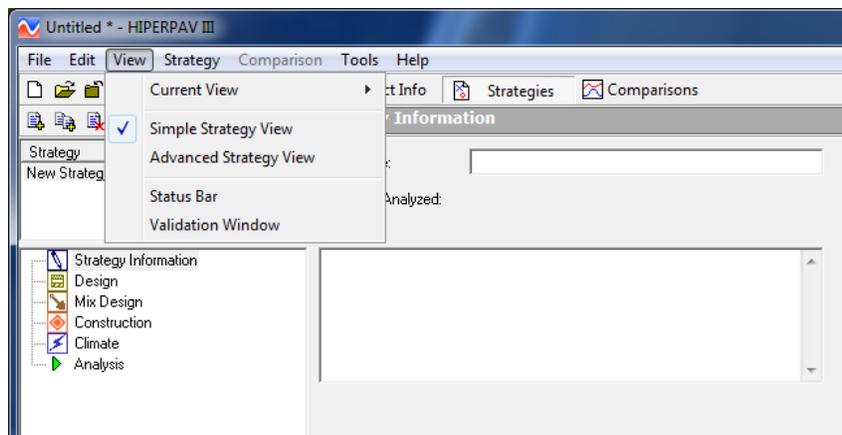


Figure 7. Screen Capture. Drop-down menu that appears beneath View in the main toolbar.

No matter which view the user chooses, the analysis performed by the software for early-age cracking potential is the same, that is, the same models are used to calculate strength gain and stress development. The input windows for the categories in the Simple View have been pared

down to prompt the user for data on only the most critical input variables. Variables for which there are no input fields are assigned default values, which are used by the models for analysis. In the Advanced View, the user has the ability to enter values for more variables, making the analysis using the same models more job-specific and thereby more accurate.

Strategy Toolbar

The strategy toolbar is provided to create, add, delete, and analyze strategies. It includes the commands shown in figure 8:

-  Add a strategy.
-  Copy the currently selected strategy.
-  Delete a strategy.
-  Validate a strategy to verify that inputs are within allowable ranges.
-  Run an analysis for the currently selected strategy.

Figure 8. Screen Capture. Commands on the strategy toolbar.

Multiple strategies can be created for a single project. To perform any of the functions listed in the strategy toolbar (except add a strategy), the strategy for which the function will be performed must be highlighted. This can be done by simply clicking the strategy of interest.

Strategy Information

Strategy Information is the first category of input windows under the main section labeled Strategies. In both Simple and Advanced Views, there is only one input window, which includes input fields for user name and comments.

Design

Design is the second category of inputs in the Strategies section. The user can enter values using either metric or United States Customary Units (USCS). Units of measure for all inputs are set to USCS by default. They can be changed to metric units in one of the following two ways:

1. The user can choose a unit of measure for each input individually. This is done by clicking the drop-down menu that appears next to each input and selecting the desired option.
2. The user can choose a unit of measure for all inputs at once. To do this, the user must click Tools in the main menu, scroll down to Options, and choose either Metric or USCS and click Apply.

HIPERPAV® can also convert from one unit system to the other for individual inputs. To convert from one unit to another, check the Convert Value box and click the desired unit in the drop-down menu next to each input where it applies.

General

In the Simple View, fields of inputs for reliability level, geometry, and slab support are grouped in the General window. Geometry inputs include thickness, width, and transverse joint spacing as shown in figure 9. Slab support inputs include a drop-down menu from which the user chooses the material that will be placed directly beneath the concrete layer. If the material is a subbase material (i.e., asphalt concrete, asphalt stabilized, cement stabilized, or unbound aggregate), the subbase thickness input field becomes active, and a default value of 6 inches for thickness appears automatically. The user can change this input to a job-specific value. If a subgrade material is chosen (i.e., lime-treated clay or untreated clay), the subbase thickness input field remains dark.

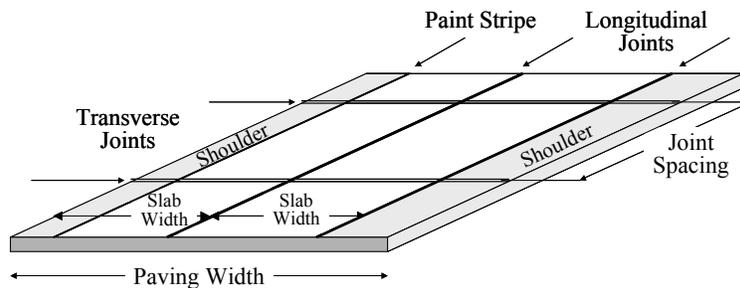


Figure 9. Diagram. Schematic of the geometry input required for a HIPERPAV® analysis.

In the Advanced View, reliability level and geometry are grouped in the General window (see figure 10), while slab support inputs are in a separate window. In the Advanced View, there are additional inputs for subbase support, which include subgrade stiffness, subbase properties, and axial restraint. There is also separate input window for dowels.

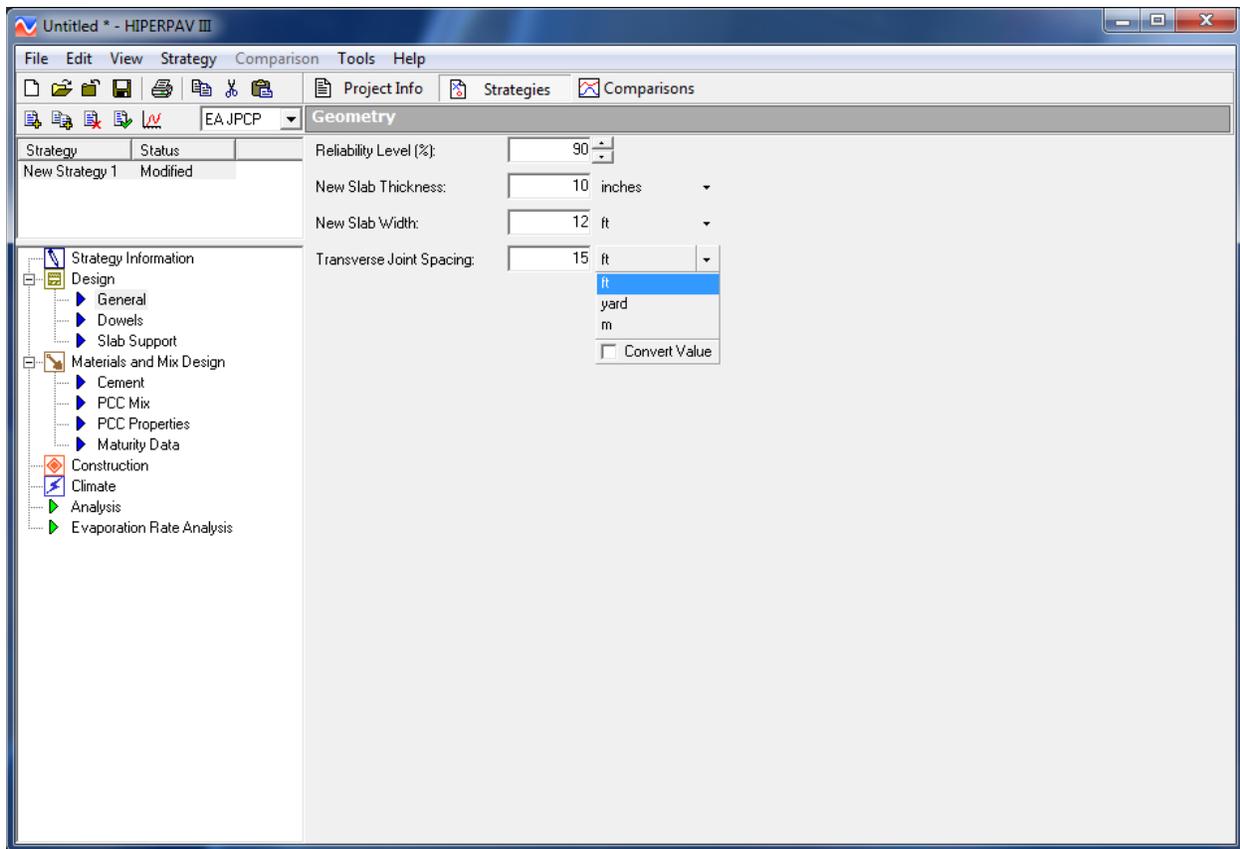


Figure 10. Screen Capture. Geometry input window under the General category.

Dowels

The Dowel input window is found under the Design category only in the Advanced View. HIPERPAV® models assess how dowel bars affect the early-age behavior of the joint in jointed concrete pavements by calculating the change in bearing stress of the dowel on the concrete as a function of temperature and time. If the bearing stress is greater than the concrete’s early-age bearing strength, then it is probable that the dowel will loosen in the pavement at a faster rate than if the bearing stress was designed to be less than the concrete’s bearing strength. Cyclic loadings, particularly during the early age, commonly cause crushing of the concrete at the dowel interface owing to the high stresses at those locations. Voids at the dowel-concrete interface will eventually cause the dowel to provide reduced load transfer efficiency.

If the user desires to evaluate dowel bearing stresses, then the dowel size, Poisson’s ratio, and modulus must be entered (figure 11); default values appear automatically in the input fields. In addition, the 28-day effective modulus of dowel support is required. The modulus of dowel support is defined as “the bearing stress in the concrete mass developing under unit deflection of the bar.”⁽³⁾ Default values are automatically provided as inputs, but should be modified to job-specific values. It should be noted that if dowels are being considered in the analysis, additional information is required on concrete compressive strength in the PCC Properties window under the Materials and Mix Design category; this is explained in more detail in the subsection later in this chapter entitled PCC Properties. In addition, a third analysis category appears (see figure 11).

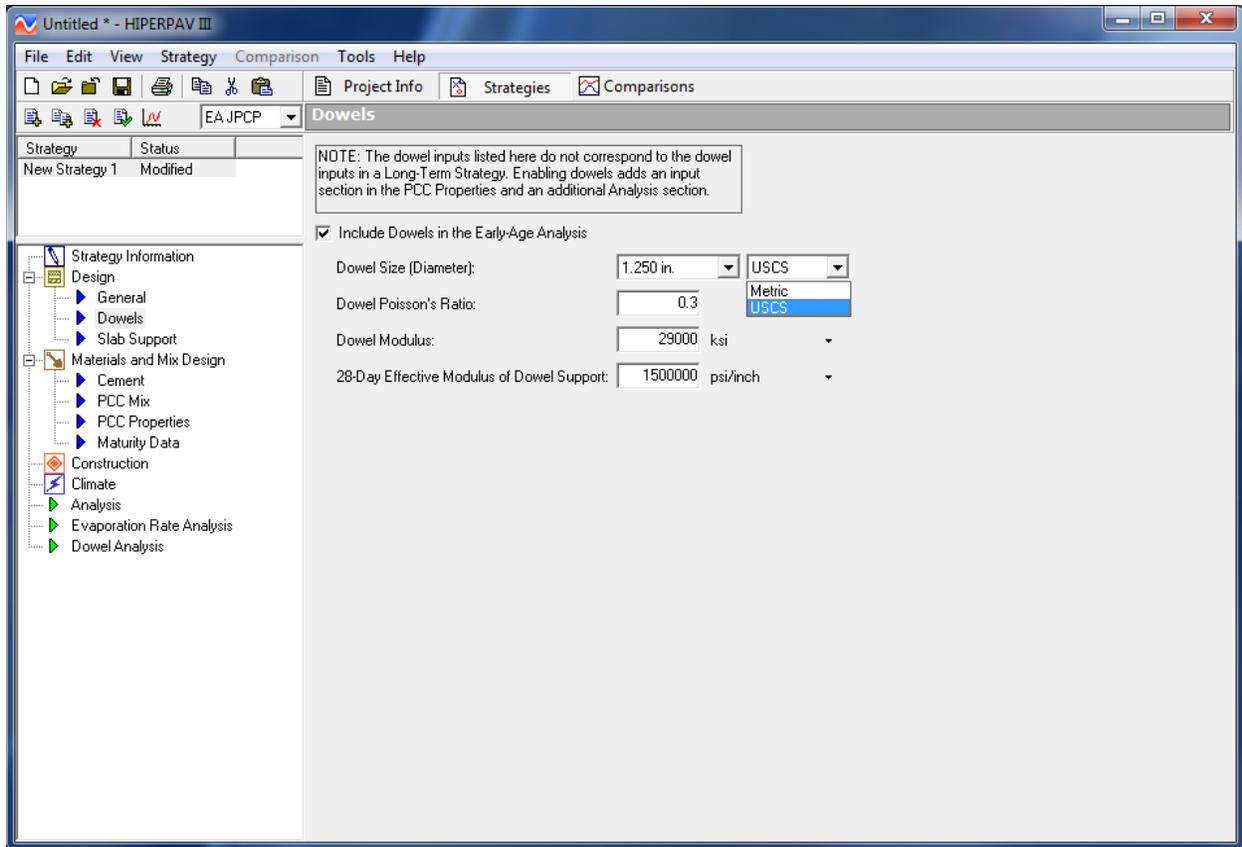


Figure 11. Screen Capture. Inputs for the Dowels window.

Slab Support

In the Advanced View, input fields for slab support are grouped and include subbase material, subbase properties, subgrade stiffness, and axial restraint. See figure 12.

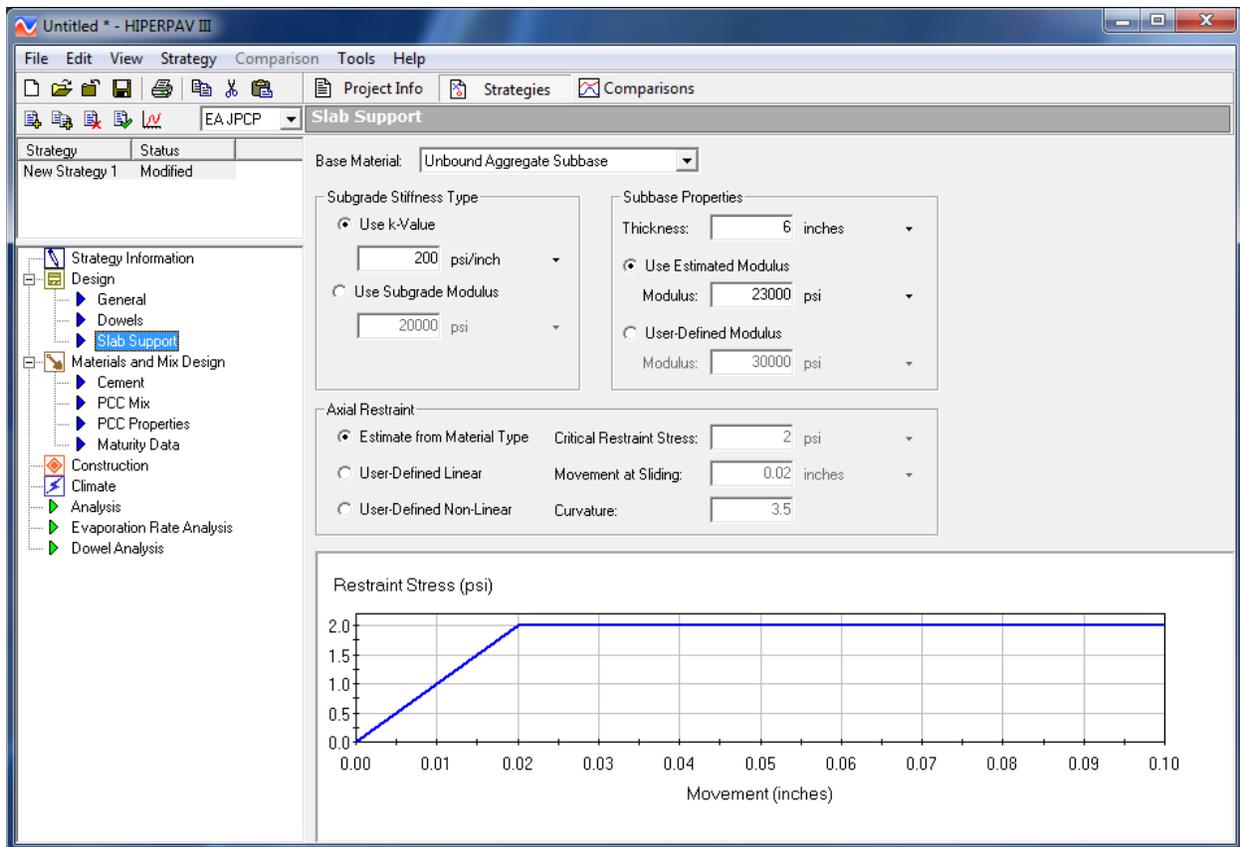


Figure 12. Screen Capture. Slab Support input window in the Advanced View.

Subbase Material and Subbase Properties. The user chooses what material will be placed directly beneath the concrete pavement layer from a drop-down menu similar to that found in the Simple View. If the material is a subbase material, input fields for subbase thickness and subbase estimated modulus values become active and include default values. The user can change these values to job-specific values. If the user chooses a subgrade material from the drop-down menu, however, then the aforementioned input fields do not become active. Only the subgrade stiffness values can be modified.

Subgrade Stiffness. Either a k -value or modulus value can be used to define the subgrade stiffness input. The user chooses between the two by clicking the option button next to the desired input option. Once the option button is clicked, the input field that corresponds to that choice becomes active. Data for job-specific k -values or subgrade modulus values can be obtained in three ways: 1) correlations with soil types and other subgrade support tests (i.e., California bearing ratio, R -value, etc.); 2) determination of elastic modulus of individual layers (e.g., with the use of deflection testing) and backcalculation methods; or 3) plate load testing.

Examples of standard test methods for obtaining elastic modulus data include America Association of State Highway and Transportation Officials (AASHTO) T 274 *Preparation of Test Specimens of Bituminous Mixtures by Means of California Kneading Compactor*, which may be used to characterize relatively low stiffness materials such as natural soils, unbound granular materials, stabilized materials, and asphalt concrete. Alternatively, the repeated-load

indirect tensile test method ASTM D 4123 *Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures* may be used to test bound or higher stiffness materials such as stabilized bases and asphalt concrete. The elastic modulus of base materials with a high cement content may be obtained with the ASTM C 469 *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression* test method.

Axial Restraint. Default axial restraint values are based on a linear relationship between critical restraint stress and movement at sliding. These values change automatically based on the type of subbase material chosen from the drop-down menu. The user can, however, modify these values to be job-specific by choosing user-defined linear or user-defined nonlinear options and then entering the appropriate values for critical restraint stress, movement at sliding, and curvature, which can be obtained from restraint tests. A restraint, or pushoff test, consists of casting a small slab with the approximate thickness of the projected pavement on top of the same subbase type. A horizontal force is applied on one side of the slab with a hydraulic jack, and a load cell is used to measure the applied load. Dial gages are installed at the opposite side to measure the slab movement. The restraint stress is determined from the applied force divided by the area of the test slab. The testing history of restraint stress and slab movement during the pushoff procedure is recorded, and the restraint stress at free sliding is evaluated.⁽⁴⁾

Materials and Mix Design Inputs

Materials and Mix Design is the third category of input windows under the Strategies section. In the Simple View, the inputs for cement type, aggregate type, admixtures, fly ash, batch proportions, and PCC 28-day strength values are grouped in one window. That is not the case in the Advanced View, however. Cement type has its own input window and includes additional input fields to better characterize cement properties. Aggregate type, admixtures, fly ash, and batch proportion inputs are grouped in a second window. Strength inputs and additional inputs for other PCC properties are grouped in a third window. Finally, maturity data inputs are grouped in a fourth window.

Cement

The Cement input window, shown in figure 13, includes input fields for cement properties and the Blaine Fineness Index. To define cement properties, the user can choose an ASTM cement type classification (drop-down menu shown in figure 14), enter user-defined percent values for oxides, or enter user-defined percent values for Bogue compounds. If selected, the user-defined oxides or Bogue compounds are entered in tabular form. The Blaine Fineness Index can be estimated from the cement type or user-defined if this information is available.

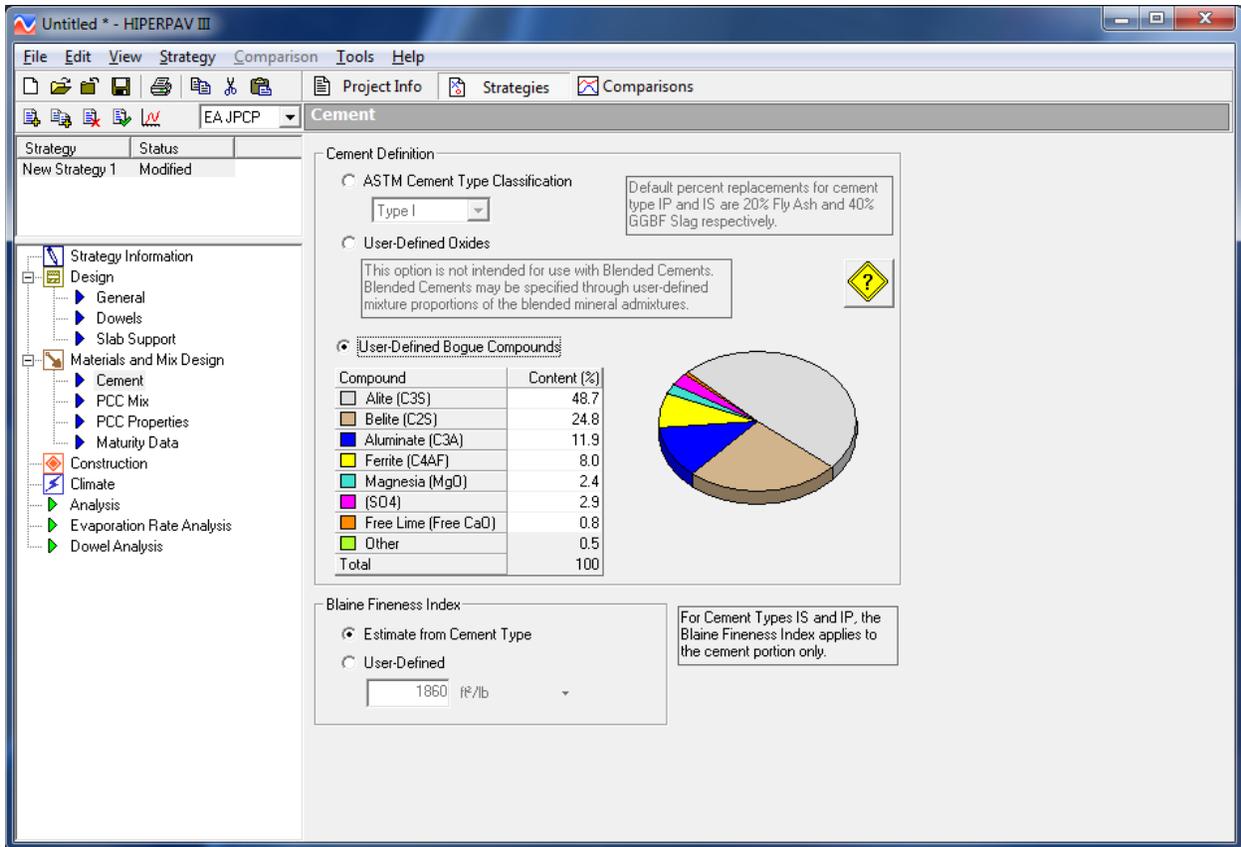


Figure 13. Screen Capture. Inputs for the Cement window.

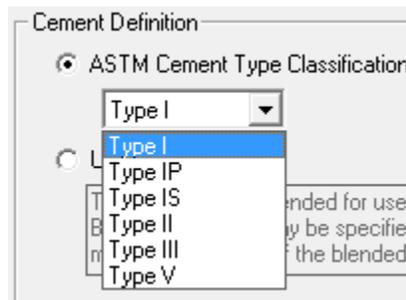


Figure 14. The list of available cement types.

A help window can be accessed by clicking the yellow icon with a question mark (see figure 15). The information in this window explains how heat of hydration is affected by different cementitious materials (see figure 16).



Help icons are provided in several software windows to provide additional guidance on the proper selection of inputs.

Figure 15. Screen Capture. Help icon.

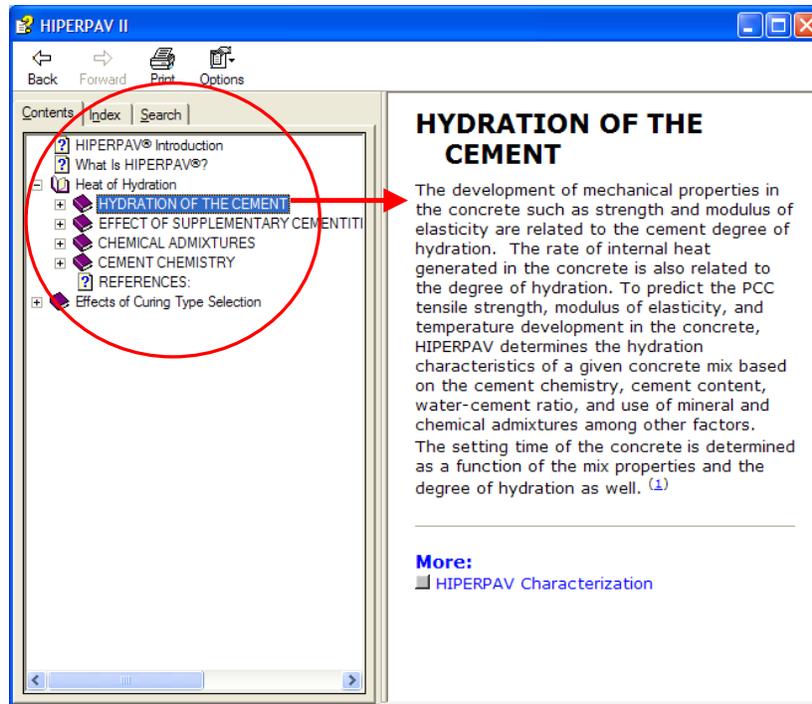


Figure 16. Screen Capture. Heat of Hydration help window in version 3.3.

PCC Mix

The PCC Mix window is used to enter the mix design inputs (figure 17), which include input fields for aggregate type, admixture type, fly ash, and batch proportions.

The type of coarse aggregate used in the mix is selected from a drop-down menu (see figure 18). The option for slag aggregate is new in version 3.3. Only version 3.3 and versions thereafter have the ability to analyze the risk for early-age cracking of JPCP projects in which the coarse aggregate of the PCC mix is a slag aggregate.

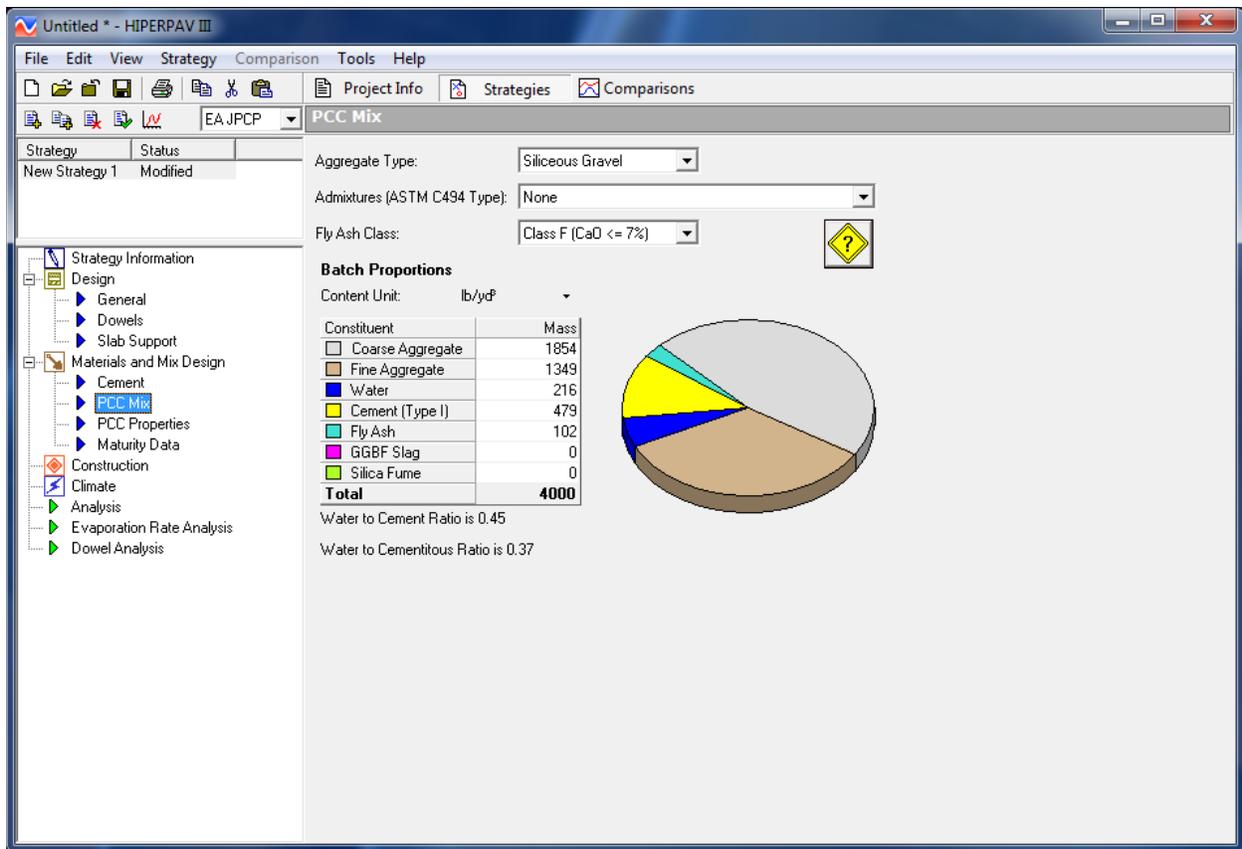


Figure 17. Screen Capture. Inputs for the PCC Mix window.

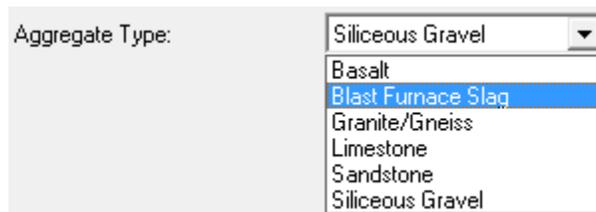


Figure 18. Screen Capture. List of available coarse aggregate types in the PCC Mix window.

The type of chemical admixture used is also chosen from a drop-down menu that lists types as defined by ASTM C 494 *Standard Specification for Chemical Admixtures for Concrete*. Note that Type A and F are not included because they would not affect the analysis (hover over the input cell at the top of the drop-down menu to see tool tip). If fly ash is used, it is necessary to specify the fly ash class and approximate calcium oxide (lime) content for Class F (see drop-down menu in figure 20). Default batch proportions by mass are provided and should be adjusted by deleting those default values and entering job-specific inputs.

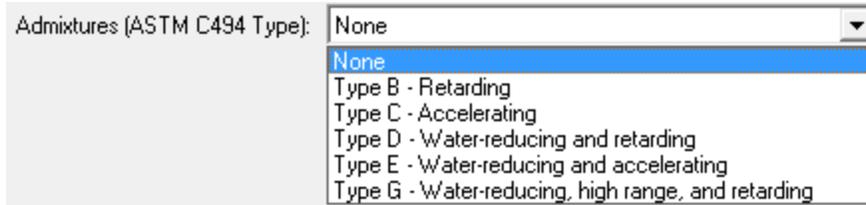


Figure 19. Screen Capture. List of available admixture types in the PCC Mix window.

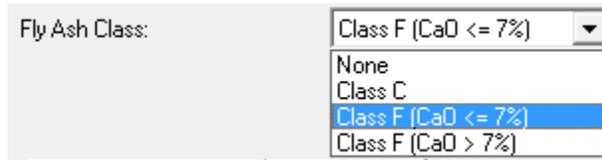


Figure 20. Screen Capture. Fly ash class drop-down menu.

PCC Properties

The PCC Properties input window includes input fields for 28-day strength, concrete coefficient of thermal expansion, 28-day modulus, and ultimate drying shrinkage (figure 21). In addition, heat of hydration inputs can be entered, which was a new addition in version 3.2.

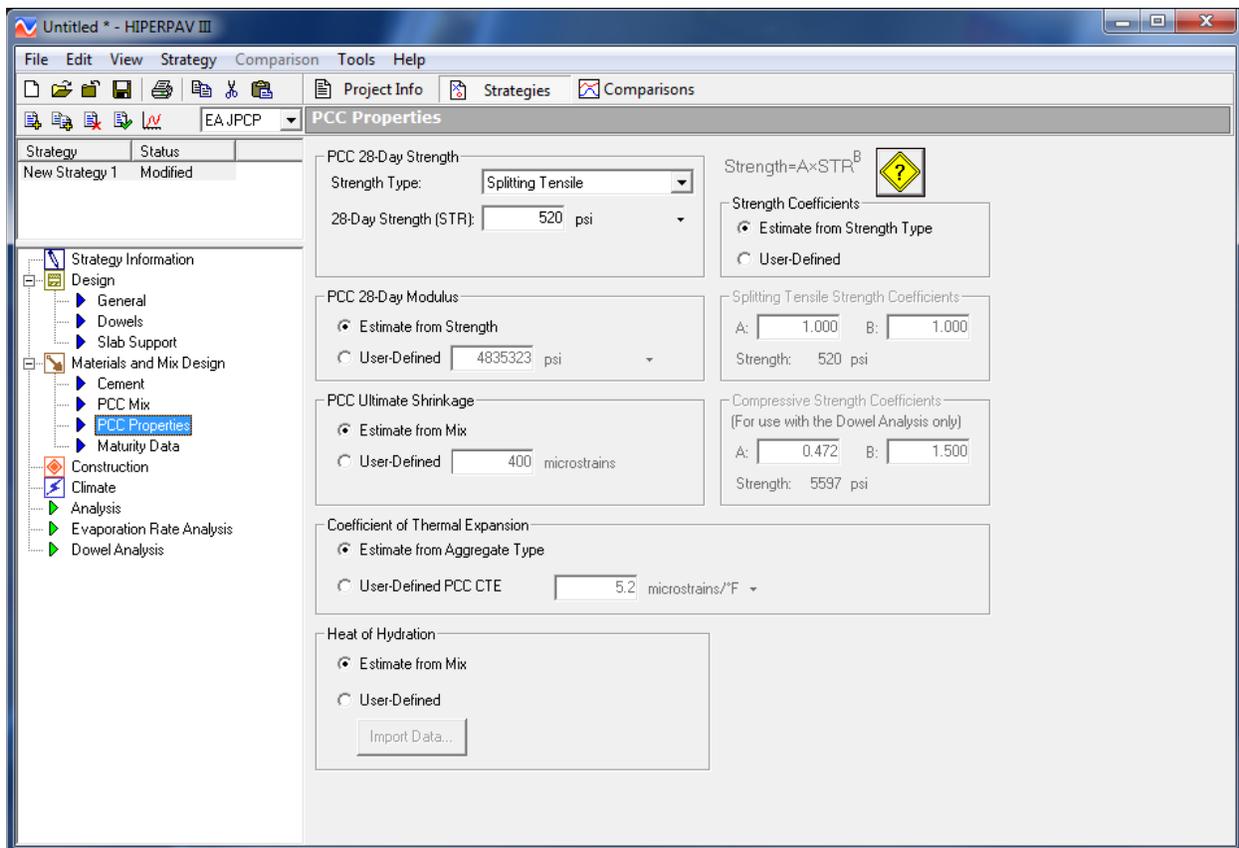


Figure 21. Screen Capture. PCC Properties window for early-age JPCP analysis.

28-Day Strength. The 28-day strength value is automatically set to a default value for splitting tensile strength (STS) of 520 psi. The user should enter tensile strength values that correspond to test results obtained for the job-specific mix. The STS is used to predict the formation of cracks in the early-age JPCP. Tensile strength is determined through the ASTM C 496 *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens* or AASHTO T 198 *Standard Method of Test for Splitting Tensile Strength of Cylindrical Concrete Specimens*. To enter a job-specific value, delete the default and enter the correct value.

Alternatively, the user can estimate the STS based on relationships with other strength types (see drop-down menu in figure 22). In the equation shown next to the 28-day strength inputs, “STR” is the PCC 28-day strength type. The user can choose to enter data for 28-day compression or flexural strength tests, and the equation will automatically calculate the tensile strength. Notice that there are strength coefficients in the equation. These coefficients can be estimated using default conversion factors; however, the user is cautioned to develop project-specific coefficients based on laboratory testing for the mix being studied (see figure 23).

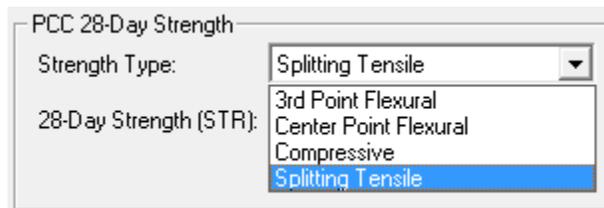


Figure 22. Screen Capture. List of options for Strength Type in PCC Properties window.

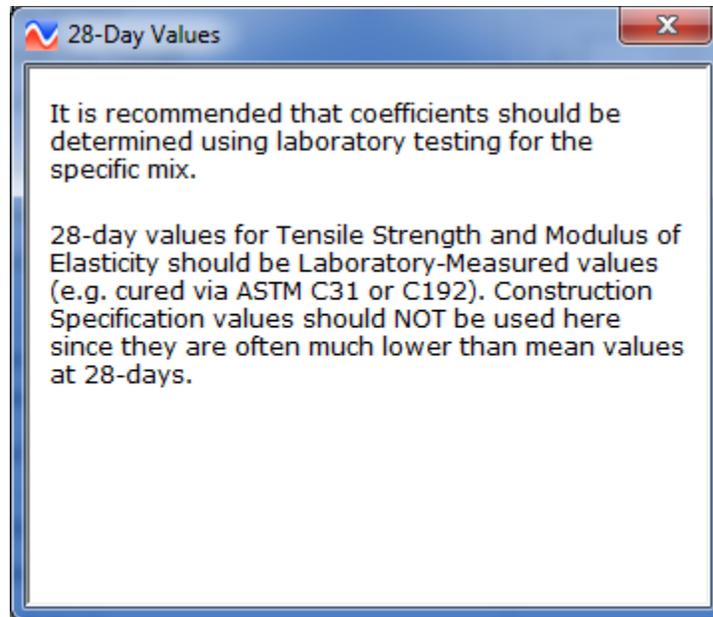


Figure 23. Screen Capture. Information provided by clicking the help icon under PCC Properties window.

The compressive strength (CS) is used to assess dowel-bearing stresses at early ages with the dowel analysis module. If dowels are part of the design and are being considered in the analysis (i.e., in the Advanced View, in the Dowels input window, the user clicked “Include Dowels in

Early-Age Analysis”), then in the PCC Properties input window, a group of CS coefficients appear. This group of inputs becomes active only when the type of 28-day strength value is a CS value. Like the STS coefficients, these coefficients can be estimated using default conversion factors, but, it is recommended that job-specific values based on laboratory testing be used.

PCC Modulus of Elasticity. The PCC modulus of elasticity, by default, is estimated from the 28-day strength inputs. More accurate values for this input can be obtained from ASTM C 469 *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression* testing of job-specific concrete specimens.

PCC Ultimate Drying Shrinkage. PCC ultimate drying shrinkage is set at a default value that is estimated from the mix design inputs. More accurate values for this input can be obtained from the AASHTO T 160 *Standard Method of Test for Length Change of Hardened Hydraulic Cement Mortar and Concrete* test procedure at 40-percent relative humidity. This test is equivalent to ASTM C 157 *Standard Test Method for Length Change of Hardened Hydraulic Cement Mortar and Concrete*.

PCC CTE. In all versions prior to version 3.3, the default value for the PCC CTE is estimated by a model that correlates PCC CTE to coarse aggregate CTE. Default CTE values for the coarse aggregate are automatically engaged when the user chooses the aggregate type from the drop-down menu in the PCC Mix input window. Alternatively, the user has the ability to enter a known aggregate CTE, or a known PCC CTE. If the user enters a known aggregate CTE, HIPERPAV® calculates a PCC CTE based on that input.

In version 3.3, however, values reported by FHWA in *Coefficient of Thermal Expansion in Concrete Pavement Design* were incorporated as default values for PCC CTE in version 3.3.⁽⁵⁾ Using the AASHTO T 336 test method, FHWA conducted research to evaluate the PCC CTE of a number of cores taken from various sections that are a part of the Long-Term Pavement Performance program. The PCC CTE values reported by this research were lower than expected for the aggregate types within the cores. Based on a correlation of PCC CTE to aggregate CTE, FHWA results suggest that typical aggregate CTE values may be lower than those found in literature and that have been used as default values in previous versions of HIPERPAV®.

It was decided that recent work by FHWA represented the most up-to-date information and more accurate values for PCC CTE. Therefore, these values were incorporated in version 3.3. It is important to mention that although the previous default values in the HIPERPAV® software are considerably higher than those measured via AASHTO T 336, the CTE values actually used for calibration of the software were laboratory measured values that are in agreement with AASHTO T 336. Sensitivity analyses were conducted to confirm the validity of HIPERPAV® models.

Heat of Hydration. Heat evolution (heat of hydration) influences thermal gradients and affects tensile stresses in early-age concrete. By default, HIPERPAV® models heat evolution using linear regression models that related heat of hydration to cementitious materials chemistry. A more accurate approach for characterizing heat of hydration was added for the first time as a feature of HIPERPAV III® version 3.2. The feature was the ability to enter semi-adiabatic test results, thereby improving the precision of the software’s mathematical models in predicting thermal stress and strength development.

In the Advanced View only, input fields for heat of hydration include “Estimate from Mix” and “User-Defined”. By default, “estimated from mix” is selected. Selecting this input instructs the software to use linear regression models to calculate heat of hydration. Choosing “User-Defined”, however, opens another window for semi-adiabatic test result inputs (see figure 24).

Calorimetry Test Data

Total Heat of Hydration (J/kg)

Estimate from Mix

User-Defined

Activation Energy (J/mole)

Estimate from Mix

User-Defined

Time, tau (hours)

Shape, beta

Ultimate Degree of Hydration, alpha

$$\alpha(t_e) = \alpha_u \cdot \exp\left(-\left[\frac{\tau}{t_e}\right]^\beta\right)$$

where, $\alpha(t_e)$ = degree of hydration at equivalent age, t_e
 t_e = equivalent age at reference temperature (21.1°C), (hrs),
 α_u = ultimate degree of hydration,
 τ = hydration time parameter (hrs), and
 β = hydration shape parameter.

Heat of hydration data should come from semi-adiabatic testing.

OK

Figure 24. Screen Capture. Illustration of the inputs for calorimetry data.

Maturity Data

Like the Dowel input window under Design, the Maturity Data input window is accessible only in the Advanced View. HIPERPAV® will estimate maturity for early-age concrete using default inputs derived from typical, normal mix designs and the 28-day strength input. However, using user-defined maturity data inputs derived from the concrete for which the HIPERPAV® analysis is being run is highly recommended. Real, job-specific maturity data inputs improve the accuracy of HIPERPAV® predicted strength gain and stress development in early-age concrete.

Maturity data should be collected in accordance with ASTM C 1074 *Standard Practice for Estimating Concrete Strength by the Maturity Method*. The standard requires casting a certain number of concrete cylinders as specimens. Sensors that measure temperature and time are embedded into several of the cylinders. Cylinders (not embedded with sensors) are then broken in compression at different time intervals within 28 days after casting. Maturity is calculated using mathematical formulas that relate strength, concrete temperature, and time.

In HIPERPAV®, users can either enter inputs obtained from the temperature-time factor method (which uses the Nurse-Saul maturity relationship), or the equivalent age method (which uses the Arrhenius relationship) for calculating maturity. For either method, maturity and strength information are entered in tabular format and automatically plotted on the window, as shown in figure 25.

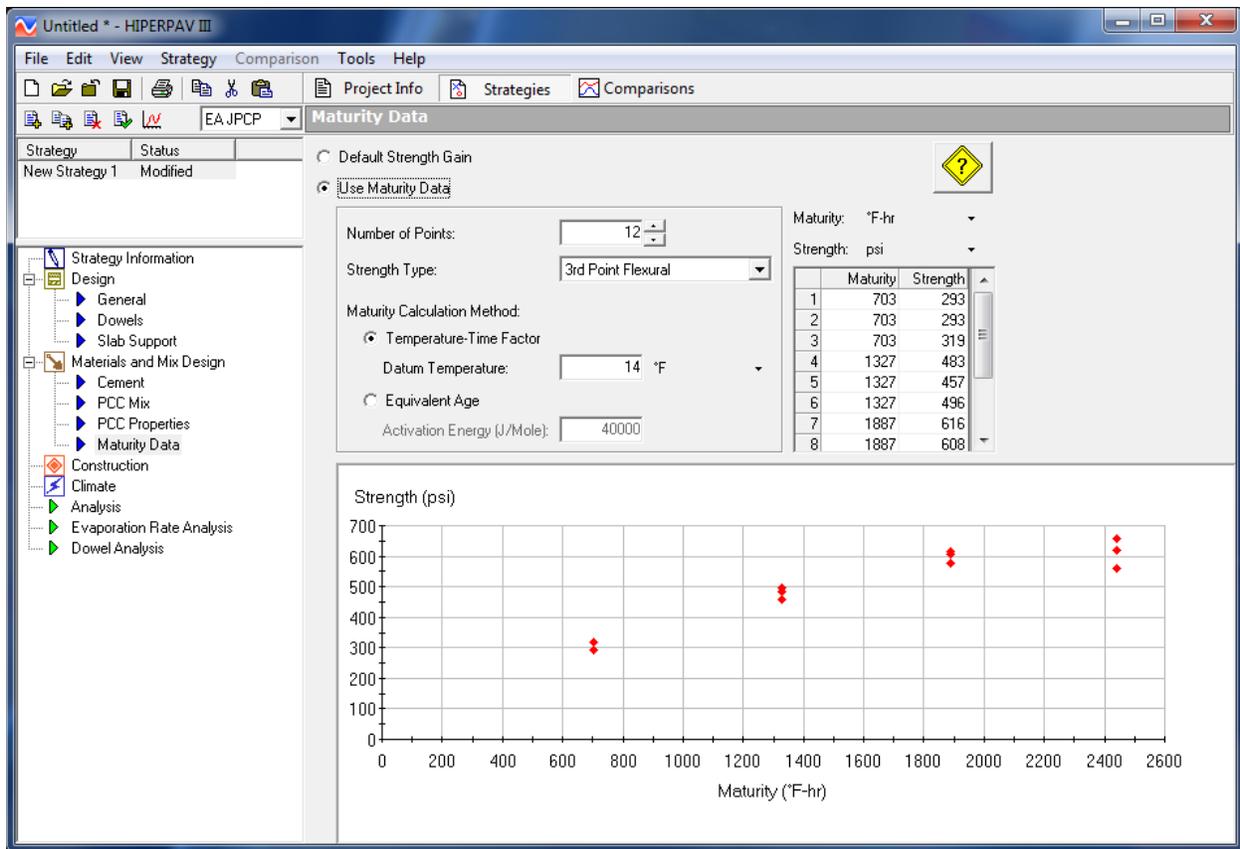


Figure 25. Screen Capture. Inputs for maturity.

Construction

The Construction category is the fourth category and consists of only one input window no matter which view (i.e., Simple View or Advanced View) is used. It includes input fields for initial conditions, curing, sawcutting, and strength for opening to traffic. An input to characterize the moisture condition of the base was added for the first time in version 3.2.

Initial Conditions

For the input fields grouped under “Initial Conditions”, default values appear in the input fields for temperature of the concrete mix, temperature of the supporting layer, and base moisture condition. It is recommended that the temperature of the supporting layer be measured at approximately 2 inches below its surface to obtain a more representative value of the average temperature in this layer.

In addition, the first of three help icons that appear in this window explains how the moist and dry options represent two extremes and advises users to opt for a dry base if there is a potential for extreme moisture loss from the slab to the base (see figure 27).

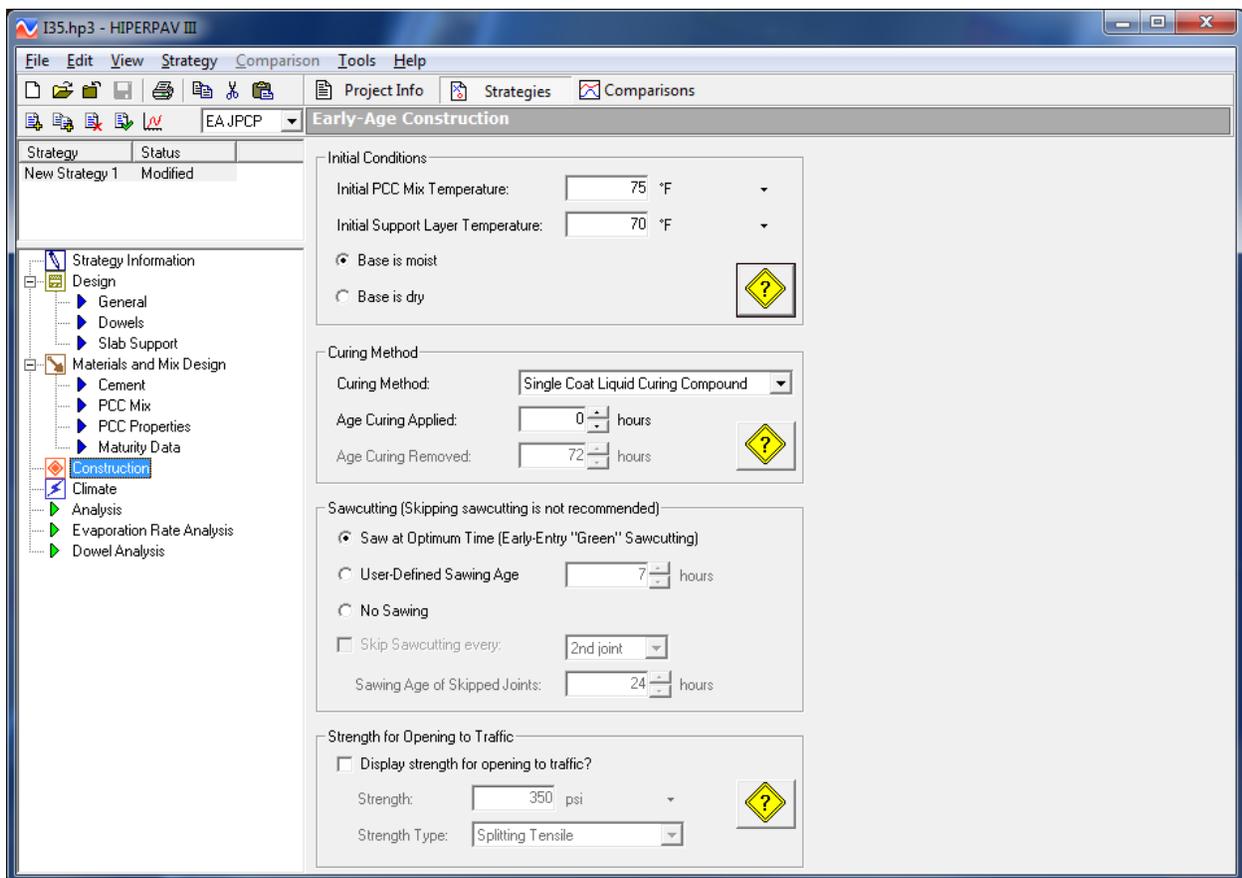


Figure 26. Screen Capture. Inputs in the Construction window.

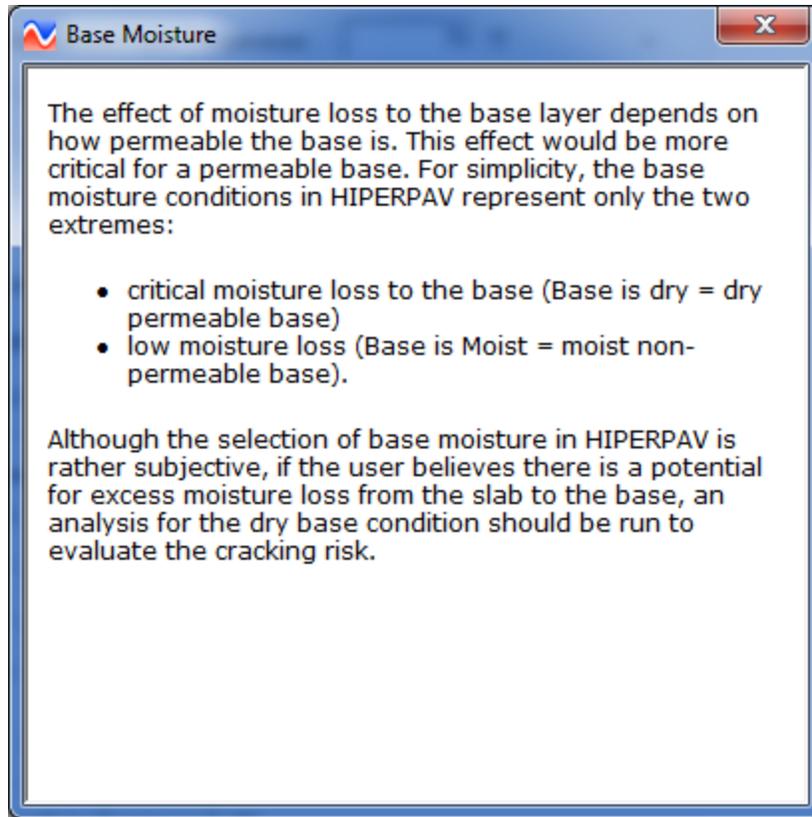


Figure 27. Screen Capture. First of three help windows.

Curing Method

Input fields for curing method and age at which curing is applied are in the next group of inputs in this window. The user is encouraged to enter job-specific inputs; otherwise, default inputs of “Single Coat Liquid Curing Compound” applied at hour “0” will be assumed for analysis. The curing method is selected from the drop-down menu shown in figure 29. The age when curing is applied is defined as the total time that elapses from when water comes into contact with cement at the batch plant to the time when the slab is covered with some kind of membrane to prevent moisture loss from the surface. If removable curing methods, such as polyethylene sheeting, are selected, the age when curing is removed is also required. A second help icon is available among the curing method inputs that includes information on the effects of curing type selection.

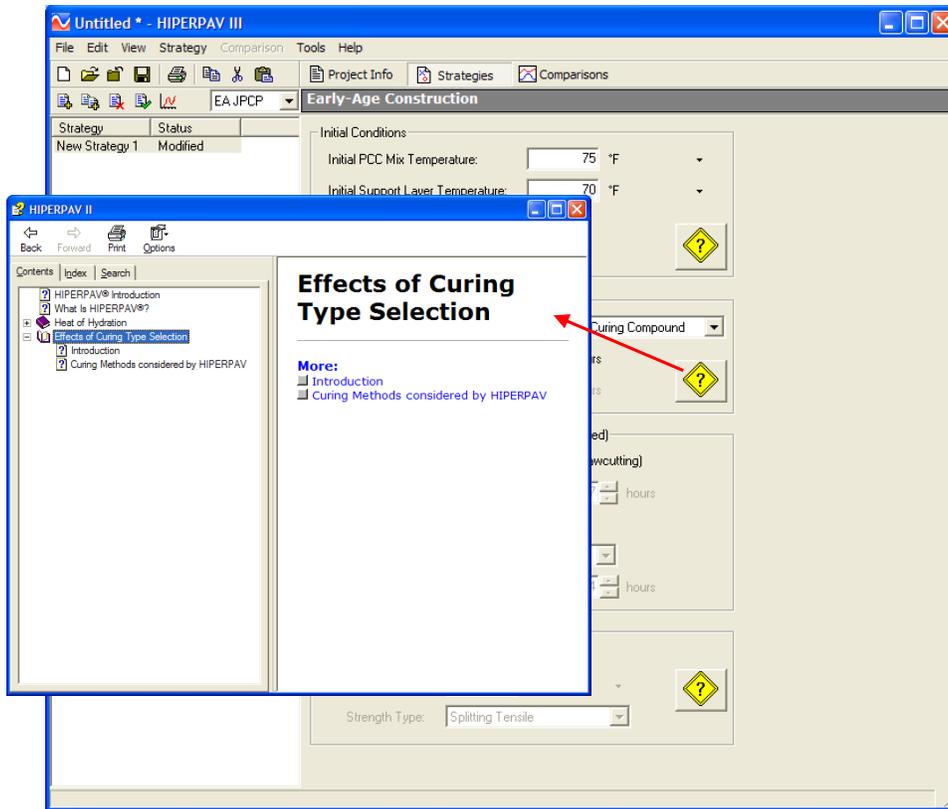


Figure 28. Screen Capture. Help window for curing.

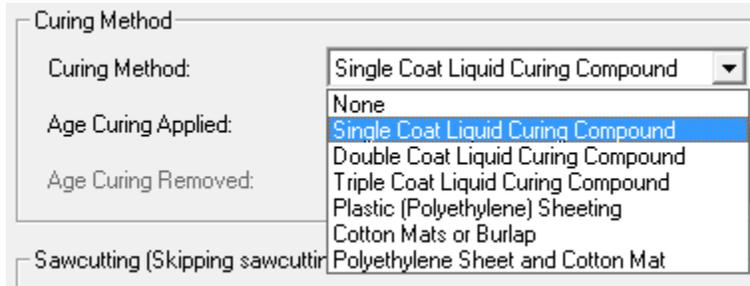


Figure 29. Screen Capture. Drop-down menu listing choices for curing methods.

Sawcutting

Inputs for sawcutting joints are entered in the next group of input fields. The following three input options are available to the user:

- **Saw at Optimum Time:** HIPERPAV® assumes that as soon as the concrete is strong enough to sawcut, the joints are formed, and HIPERPAV® performs the analysis based on the transverse joint spacing entered.
- **User-Defined Sawing Age:** HIPERPAV® simulates the stress development for a semi-infinite slab until the specified sawing age. After that time, the stress development is simulated based on the transverse joint spacing entered.

- **No Sawing:** HIPERPAV® simulates the stress development for a semi-infinite slab for the 72-hour analysis. This option is useful to estimate the latest sawcutting time. The time when the stress exceeds the strength for this scenario would correspond to the latest sawcutting time. However, this option must be used with caution because a great amount of liability is involved. It is recommended that joints be sawcut at a maximum of 18 to 24 hours after paving, regardless of predicted conditions.

Although not a recommended practice, the user may also estimate the effect of skip sawcutting for the first two options. Options for skip sawcutting, varying from every other joint to every fifth joint, may be specified in the drop-down menu next to the “Skipping sawcutting every” checkbox. If this option is selected, the user also needs to enter the time when the skipped joints are cut.

Strength for Opening to Traffic

If a given strength for opening to traffic is required, this information can be entered in the Construction inputs window. A third help icon for this input is provided (see figure 30). The user can select the strength type to be used for opening to traffic. After the analysis is run, the strength for opening to traffic is indicated in the analysis window (shown later in figure 34 and figure 35) if this strength is achieved within the 72-hour analysis period.

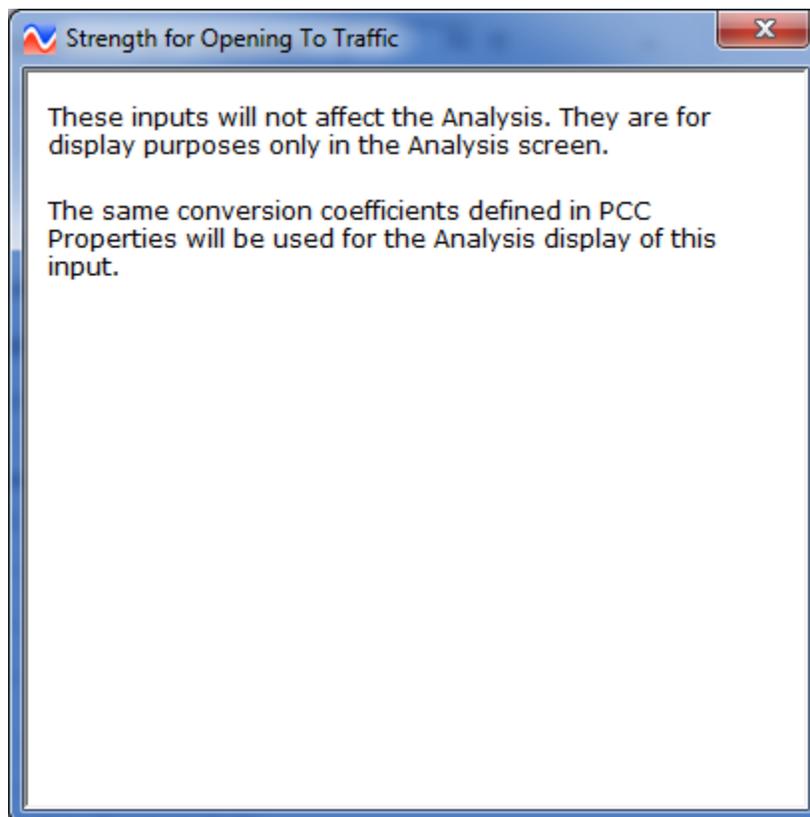


Figure 30. Screen Capture. Help window explaining strength for opening inputs.

Climate Inputs

The Climate category is the last category of input windows. In versions previous to version 3.3, the window in this category was titled Environment. Although the name of the window has changed, the input fields have remained the same and are the same for both the Simple and Advanced Views. The user enters climate data for ambient temperature, wind speed, cloud coverage, and relative humidity for the first 72 hours following construction. Each type of climatic condition has its own input window. The user can toggle between the four windows by choosing accordingly from a drop-down menu next to the phrase “Data to display”, as shown in figure 31. Data for each climatic condition appears in the respective window in two ways: listed in a table and illustrated in graphical format.

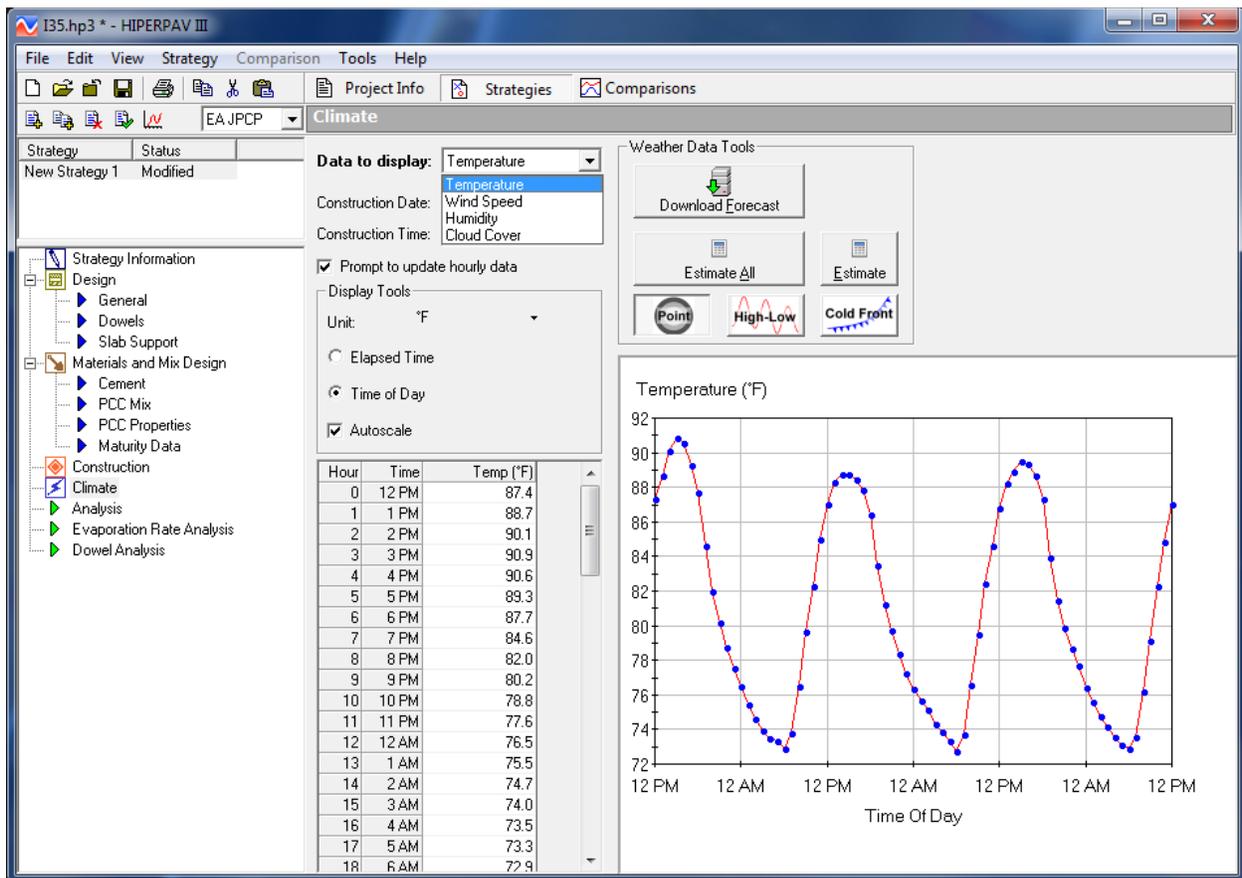


Figure 31. Screen Capture. Climate window with drop-down menu for toggling between climatic condition windows.

Construction date and time are entered below the type of climatic condition drop-down menu. Each of these job-specific inputs has its own drop-down menus from which the user can choose accordingly. By default, the box next to the words: “Prompt to update hourly data” is checked, and a window will appear with a message every time the date or time is changed. The user should click “Yes” to confirm. To cancel this prompt, the user must uncheck the box.

There are three ways climate inputs can be entered: the data can be estimated from the built-in historical database, the user can enter it directly, or the data can be downloaded from the

National Oceanic and Atmospheric Administration (NOAA) Web site. The option to download climate data from NOAA is a new, automated feature in version 3.3.

Estimating Climate Inputs

The HIPERPAV® software is equipped with an internal database of historical climatic conditions. The information in the database was assimilated from weather stations all over the country, including Alaska and Hawaii, and spans more than 30 years of climatic records. Based on the location identified in the Geography window of the Project Info section, the software automatically identifies the nearest weather stations and performs a weighted average of the historical data for air temperature, wind speed, relative humidity, and cloud cover. The averaged data are automatically entered as the default values in the Climate window.

Manually Entering Climate Inputs

Alternatively, the user can manually enter real-time data instead of historical averages. A single data point, multiple data points, or a range of data can be entered manually. To manually enter data, the user can perform one of the following two processes:

- Enter values directly into the table for specific times.
- Manipulate the graph by performing one the following steps:
 - Clicking the Point button and then dragging individual points on the plot (see figure 32).
 - Specifying high and low values for each day by clicking the High-Low button and dragging the red points (see figure 32).
 - Simulating a cold front condition by clicking the Cold Front button and dragging down the desired point (see figure 32).

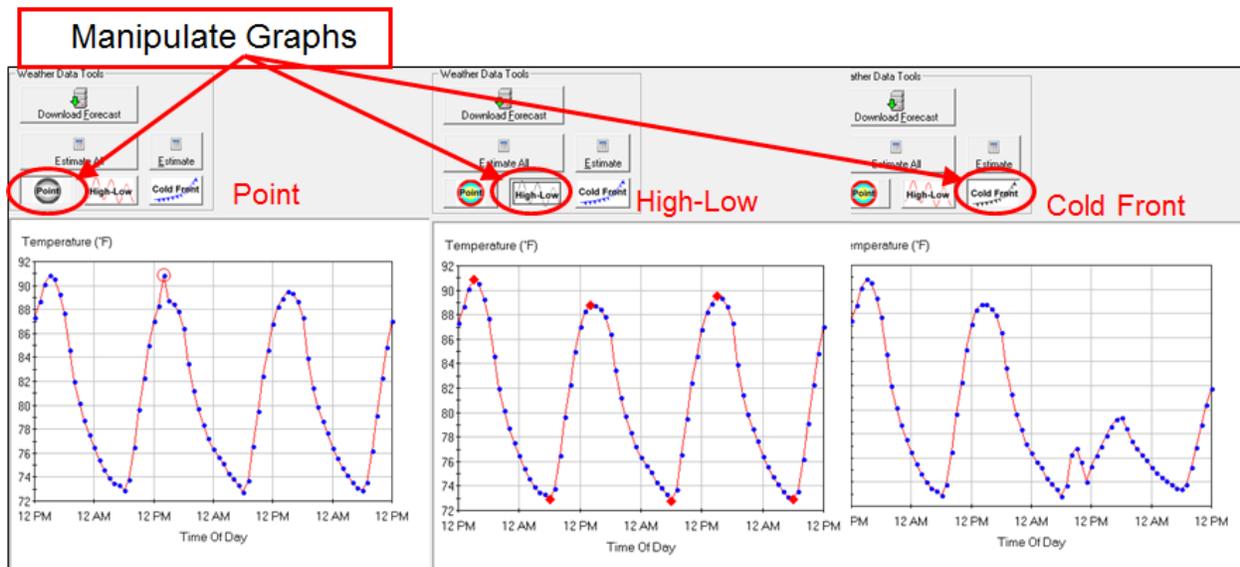


Figure 32. Screen Capture. Options available to the user for manipulating the graphs.

If the construction date or time is changed, it is important that data within each climatic condition window (i.e., ambient temperature, wind speed, relative humidity, and cloud cover) be estimated again using the “Estimate” or “Estimate All” buttons. The “Estimate” button only updates the data displayed in the current window. The “Estimate All” button updates the data in all windows. Options for plotting weather data in terms of elapsed time from construction or for time of day are provided. In addition, an auto-scale feature can be selected to cover a wider or narrower range of data.

Downloading Forecasted Climate Inputs

With version 3.3, the user can now choose to download forecast data from NOAA. To use this automated feature, there must be a connection to the Internet. Figure 31 shows the location of the “Download Forecast” button under Weather Data Tools. When the “Download Forecast” button is clicked, the ambient temperatures, wind speed, relative humidity, and cloud cover data forecasted by NOAA for the project location will be automatically entered into the software. It should be noted that the user must identify the project location in the Geography window for NOAA to provide an accurate forecast for a specific location.

With this new feature, users no longer have to manually enter job-specific weather conditions when the database does not accurately represent real conditions. However, there are a few anomalies that the user must be aware of when running and interpreting an analysis in which downloaded weather forecast data are used.

The NOAA service provides forecasted data; that means that it will report data for the future, but not for current or past conditions. What this means is that HIPERPAV® cannot use downloaded data for an analysis of a strategy in which the construction time has elapsed or is too far into the future. Any time beyond 7 days is too far in the future; there is not enough data provided by NOAA to support a complete HIPERPAV® analysis. A HIPERPAV® analysis requires 72 hours’ worth of data. If an analysis is run for a construction time that will occur at a point in time for which the NOAA service cannot provide enough (or any) forecasted data, a warning message will appear (see figure 33). In this case, HIPERPAV® will use historical data or manually entered data for the analysis.

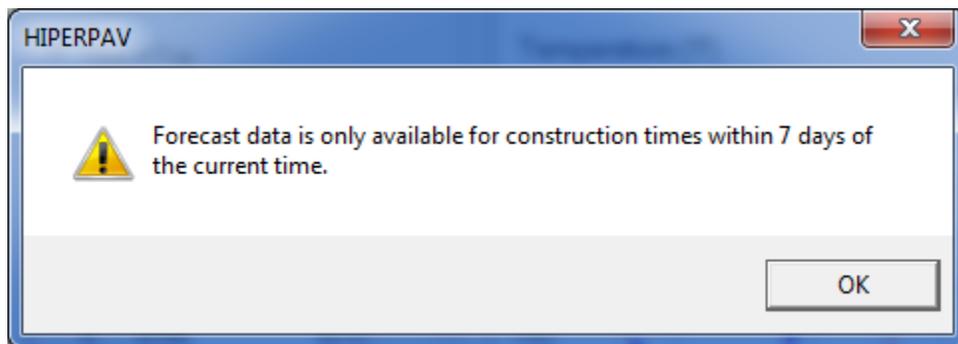


Figure 33. Screen Capture. Warning message advising user of a construction time too far into the future for which forecasted data cannot be downloaded.

NOAA provides updated forecast data every 3 to 6 hours for the first 72 hours from the current time. The number of hours for which data are provided at 3-hour intervals depends on when

during the day the NOAA service was accessed. The NOAA service provides forecasted weather data for 3- and 6-hour intervals based on a routine schedule that is a fixed feature of the NOAA service. When the user clicks the “Download Forecast” button, the forecast available at that moment in time through the NOAA service is downloaded into HIPERPAV®. Whether or not data provided by the service are at 3- or 6-hour intervals, HIPERPAV® interpolates between the intervals so that values exist for every hour of the analysis period.

Analysis

Once the user has entered all of the inputs into the Design, Mix Design, Construction, and Climate input windows, an analysis can be run. Clicking the  icon found in the Strategy toolbar will begin the analysis process. After clicking the icon, the Analysis window appears. If the user is in Simple View mode, the Analysis window will resemble figure 34. If the user is in Advanced View mode, the Analysis window will resemble figure 35.

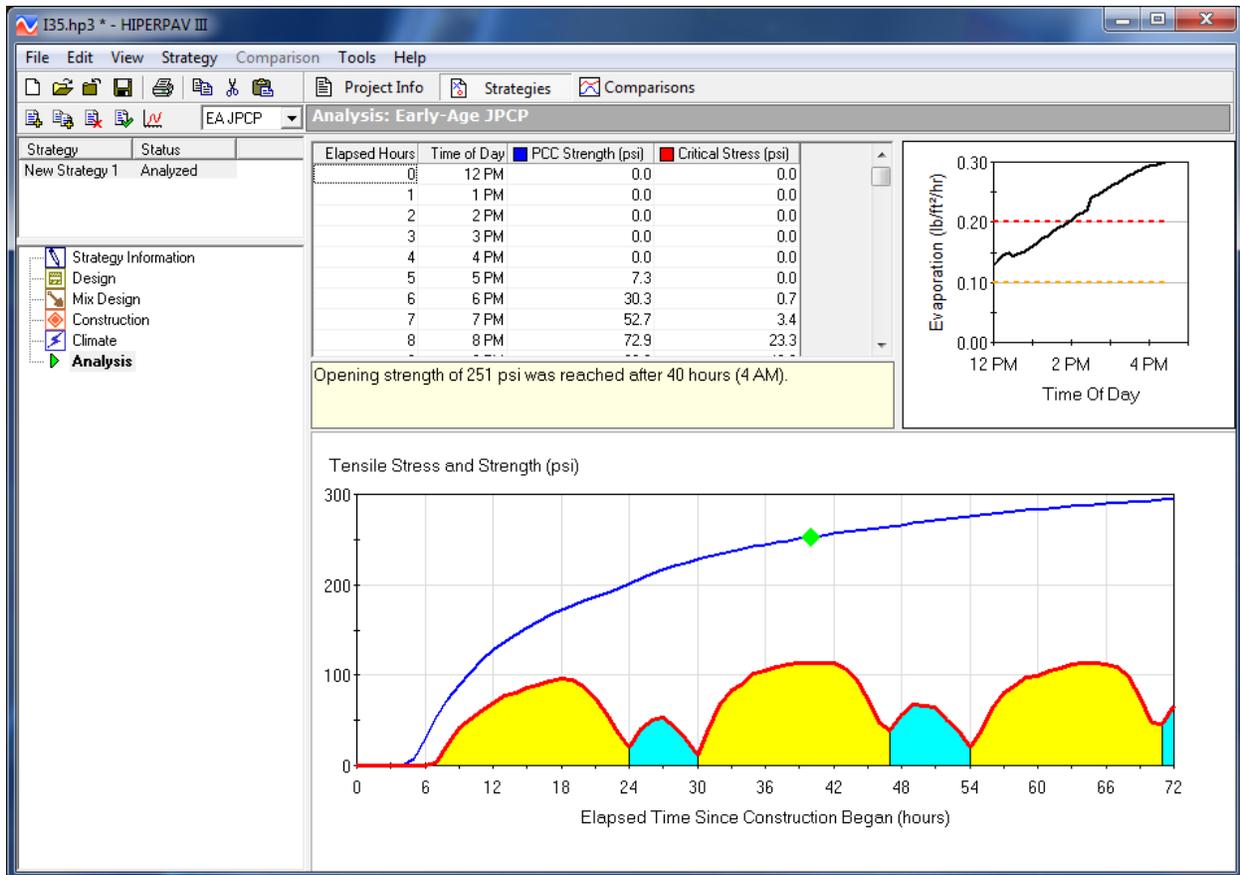


Figure 34. Screen Capture. Simple View analysis window for early-age JPCP.

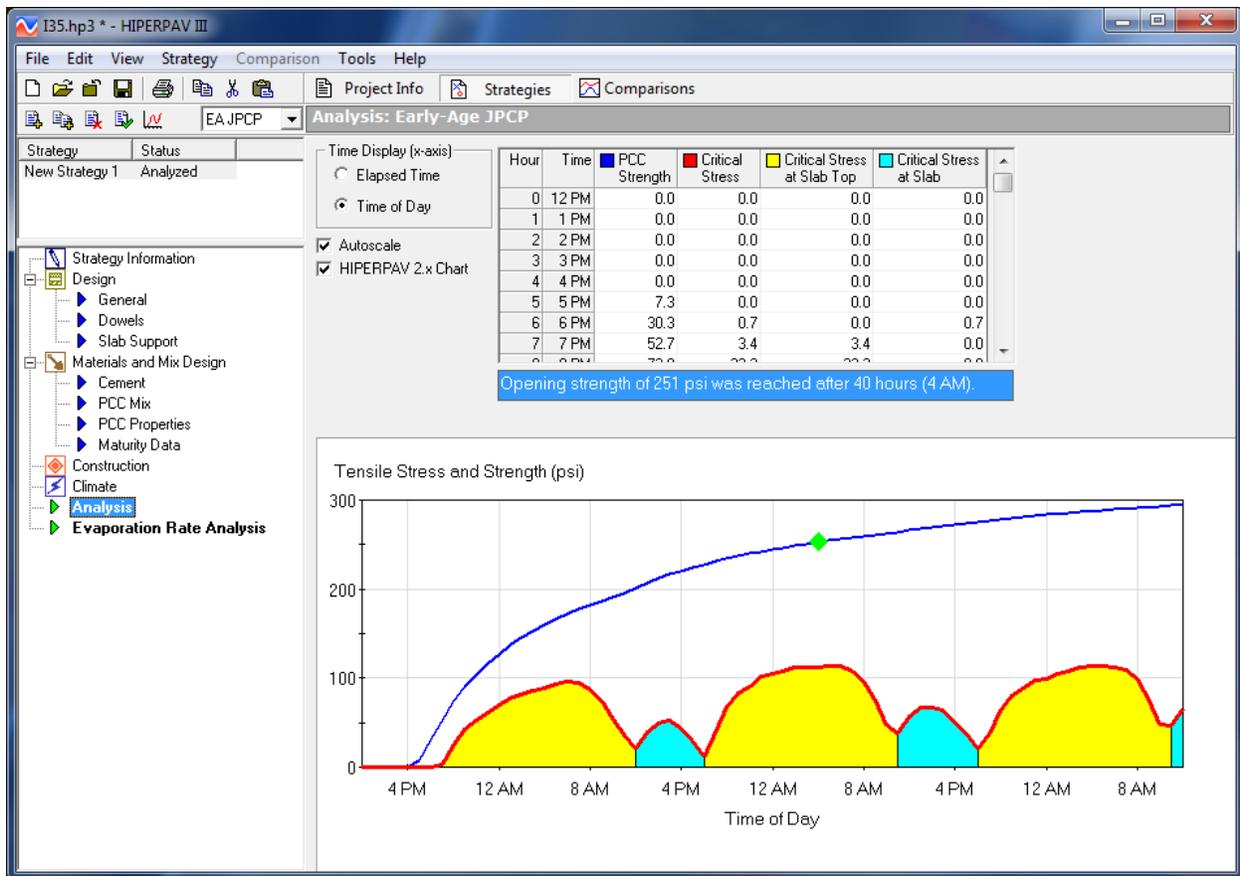


Figure 35. Screen Capture. Advanced View Analysis window for early-age JPCP.

Notice that the only difference between the two windows is that for the Simple View, the evaporation analysis is shown in the upper right-hand corner. For the Advanced View, the evaporation analysis appears as a separate window. The information that is presented in both views includes PCC strength and critical stresses. This information is presented in a tabular and graphical format. The numerical value of tensile stress and strength can also be obtained by hovering the mouse over the point of interest on the graph. In addition, if the user checks the box next to the words “Display strength for opening to traffic?” found at the bottom of the Construction window, then a note above the graph and a green point along the strength gain curve on the graph will appear indicating when the proper strength for opening to traffic is achieved (see figure 34 and figure 35).

Interpretation of Analysis Results

HIPERPAV® executes a series of powerful algorithms that calculate the PCC pavement stress and strength development continuously for the first 72 hours following placement. The user is presented with a graphical window, which plots the results of the analysis as they are computed in real time. The user can observe the trend of the strength and stress development and assess the risk for early-age cracking based on the specific user inputs.

Figure 35 shows outputs from a typical analysis of a strategy in which the combination of pavement design, mix and materials design, construction methods, and climate conditions

suggests a low risk for early-age cracking, or a high probability of good performance. This can be concluded with comfortable certainty because the strength curve (blue line) remains above the stress curve (red line) at all times during the first 72 hours. Note the cyclical manner in which the critical stress occurs. Peaks in the stress curve occur at critical periods when either tensile stresses at the top of the slab are dominant (yellow areas) or when tensile stresses at the slab bottom are dominant (blue areas); the former is in the early morning hours, and the latter is just after midday. In this scenario, the risk for PCC pavement early-age distress (random transverse cracking) is low because the stress does not exceed the strength during the first 72 hours after placement.

Figure 36 shows an Analysis window for a strategy in which the combination of pavement design, mix and materials design, construction methods, and climate conditions result in a high risk for early-age cracking. The risk is high because the predicted critical stress curve exceeded the predicted strength gain curve 15, 39, and 63 hours after construction.

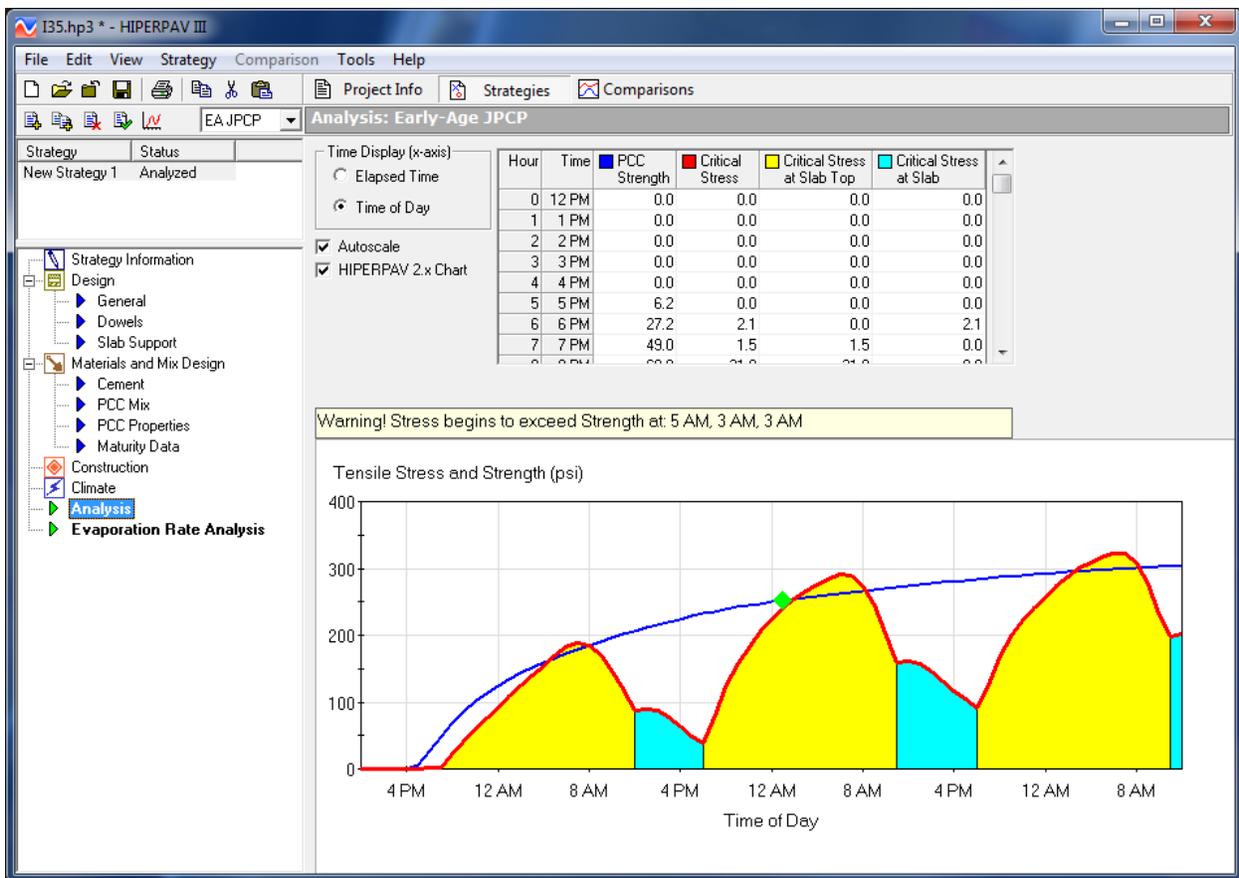


Figure 36. Screen Capture. Advanced View Analysis window showing high risk for early-age cracking.

Evaporation Rate Analysis

The Evaporation Rate Analysis window is shown in figure 37. This analysis is a function of the wind speed, relative humidity, air temperature, and predicted concrete temperatures. The effect of curing methods is not considered in the evaporation rate analysis. The predicted evaporation

rate is presented in both graphical and tabular form. Because wind speed is critical in evaporation rate predictions, evaporation rate is predicted as a function of multiple wind speeds. The black curve corresponds to the evaporation rate calculated for the wind speed entered in the climate input screen.

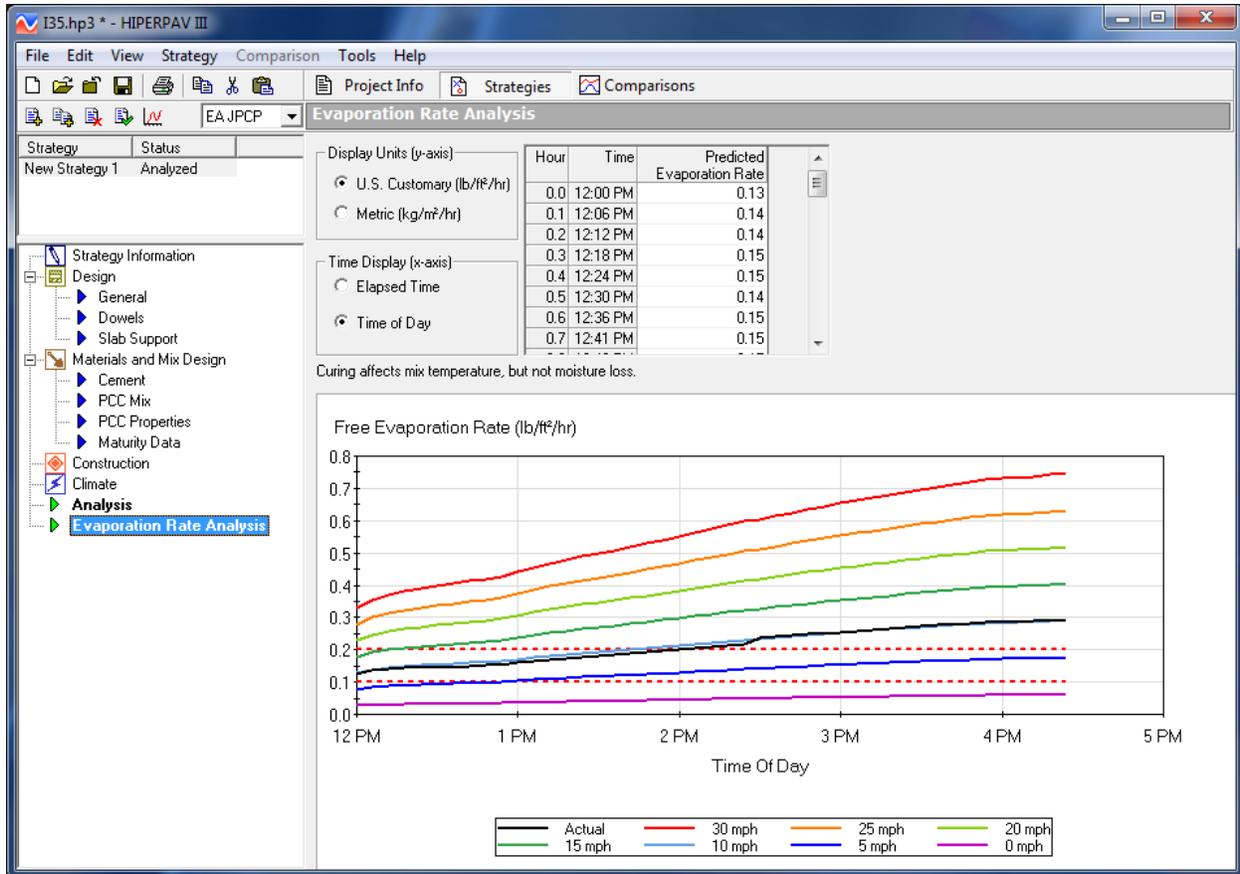


Figure 37. Screen Capture. Evaporation Rate Analysis window for early-age JPCP analysis.

Dowel Analysis

The Dowel Analysis window compares the concrete bearing strength to the bearing stress generated in proximity to the dowels owing to slab curling as shown in figure 38. Because slabs in the field may show different curling conditions from one slab to the other, the following two scenarios are considered: 1) two slabs with similar curling conditions (curl-curl stress), and 2) one slab flat and the adjacent slab in a curled shape (flat-curl stress). It is believed that the actual stress to which a concrete/dowel may be subjected would be intermediate between these two conditions. As in the Evaporation Rate Analysis window, the Dowel Analysis results are presented in both a graphical and a tabular form.

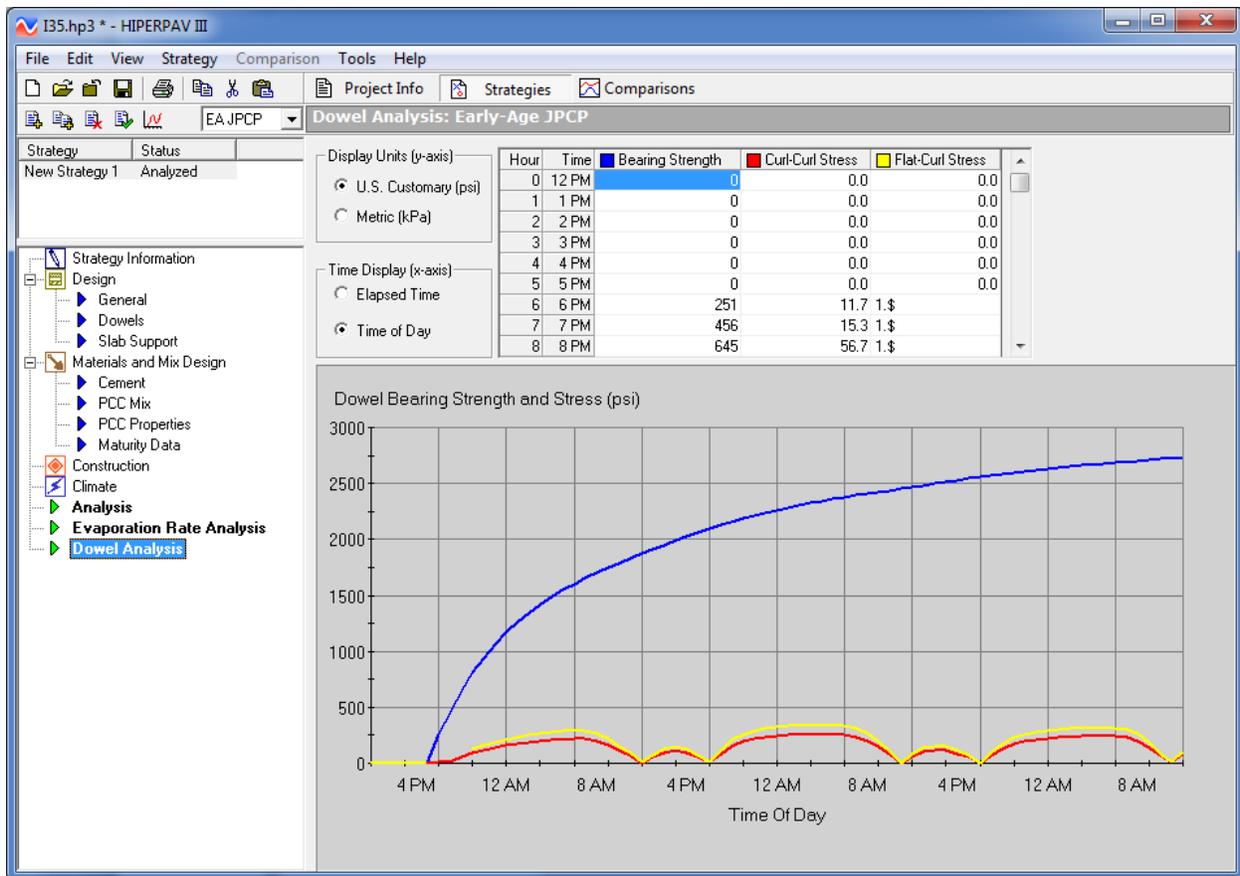


Figure 38. Screen Capture. Dowel Analysis window for early-age JPCP.

COMPARISONS MODULE

The Comparisons module was added as a new feature in version 3.2. Accessed by clicking just to the right of “Strategies” in the main toolbar, as shown in figure 43, Comparisons includes sensitivity analysis tools. Two sensitivity analyses tools are available in this module: Quick Compare and Sensitivity Comparisons.

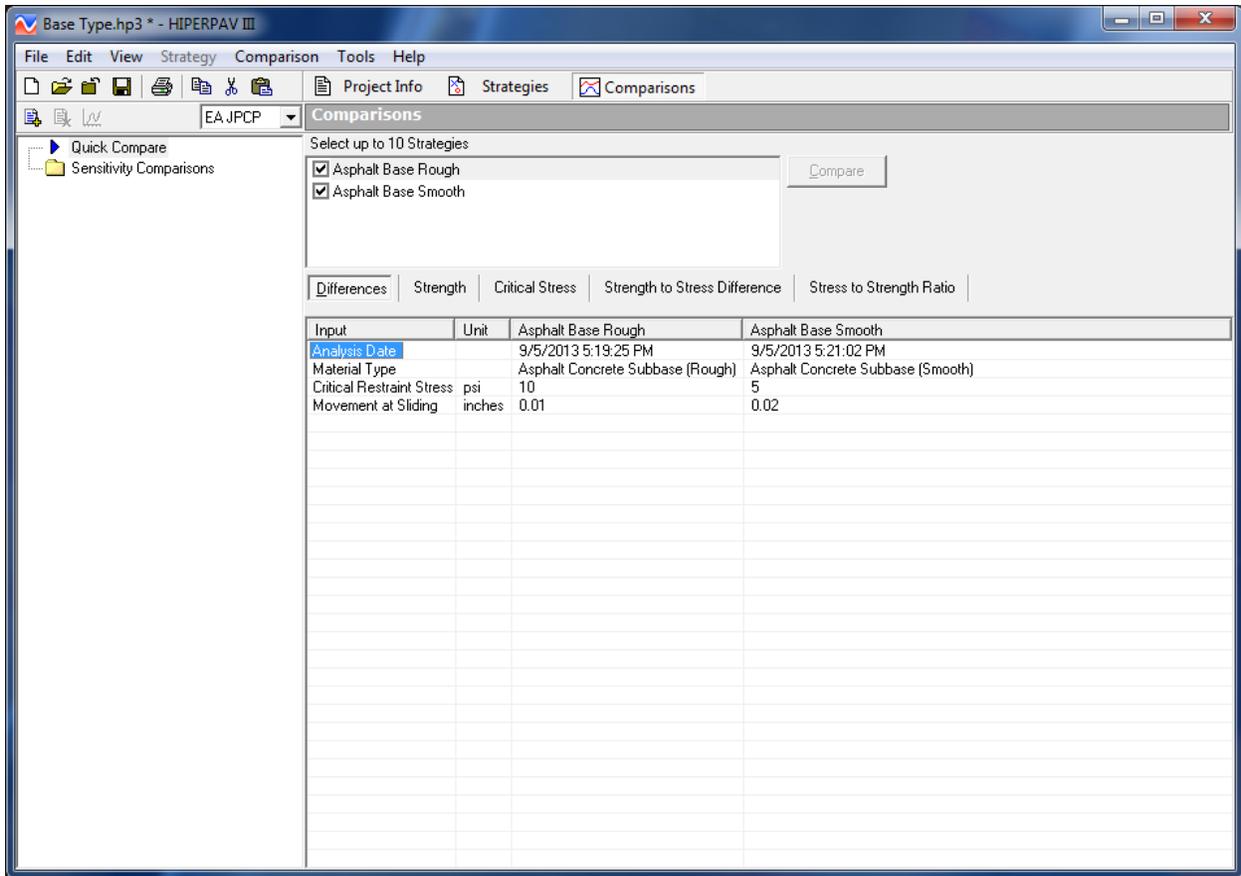


Figure 39. Screen Capture. Snapshot of the Quick Compare window showing the location of the Comparisons module in the main toolbar.

Quick Compare

Quick Compare allows the user to quickly identify the differences between strategies. The advantage of this tool is the ability to compare up to 10 individual strategies and see how their differences affect concrete properties. The user checks the strategies of interest (limit of 10) and clicks the “Compare” button. A chart that lists the elapsed time and any input differences is generated. The user can toggle between the chart and graphs that provide a visual, side-by-side comparison of strategies for properties including strength, critical stresses, strength-to-stress differences, and stress-to-strength ratios for each of the chosen strategies (see figure 40).

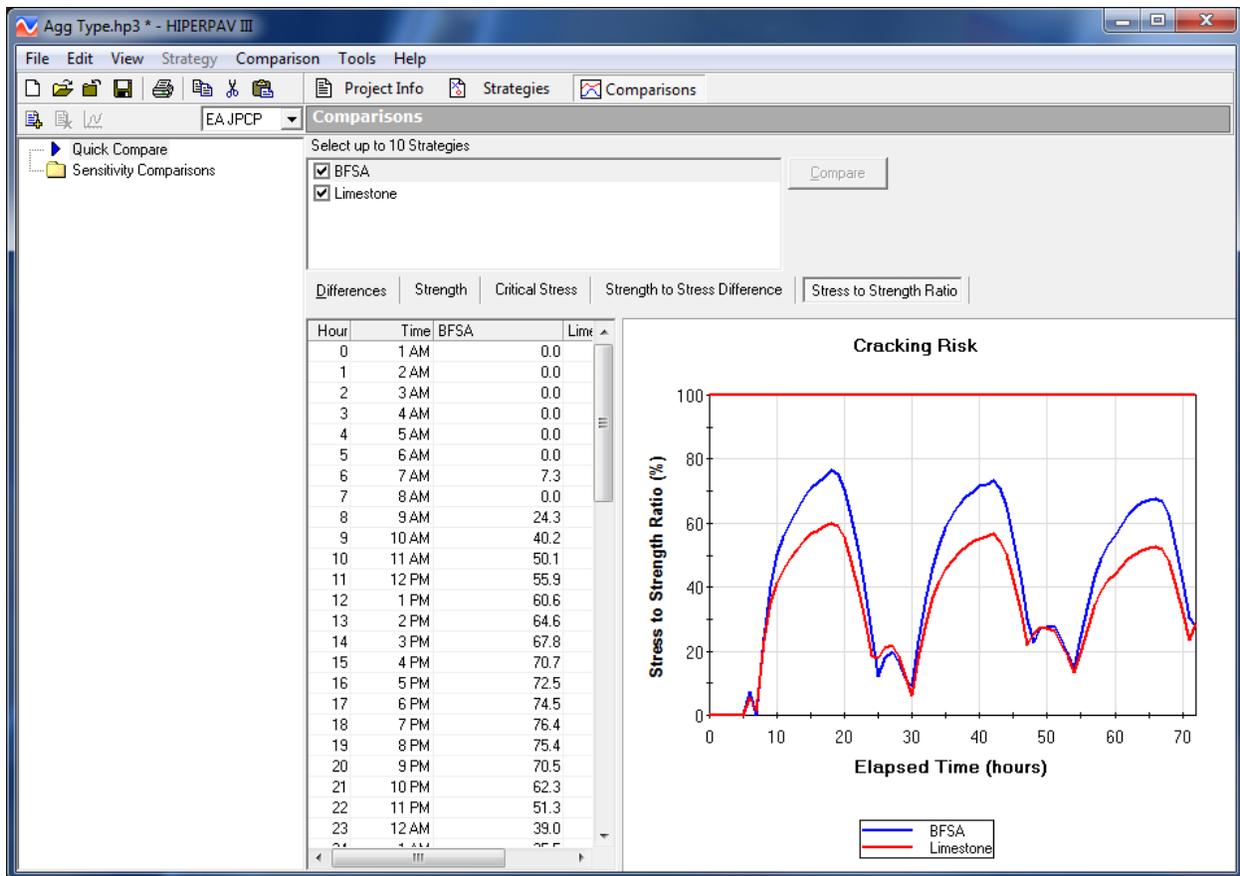


Figure 40. Screen Capture. Quick Compare Stress-to-Strength Ratio window showing a comparison of two strategies.

Sensitivity Comparisons

Like Quick Compare, the Sensitivity Comparisons tool also generates a chart and graphs, which the user can use to compare analyses. However, the user is not comparing the differences between individual strategies. Instead, this tool compares the effects of changing inputs for a single strategy.

To use this tool, add a comparison with the Add button, , located in the upper left corner of the window. An Add Sensitivity Comparison wizard window pops up, prompting the user to select the strategy of interest (see figure 41). The user then selects the input variable to evaluate, a range for that variable (if applicable), and an analysis interval. HIPERPAV® then calculates the following properties: strength, critical stresses, strength-to-stress differences, and stress-to-strength ratios for the range identified.

For example, figure 41 shows the Add Sensitivity Comparison inputs for the Initial Mix Temperature variable. A range from 50 °F to 90 °F is used. Also, an interval of 10 °F is selected so that the wizard runs an analysis for every 10 °F starting at 50 °F and ending at 90 °F.

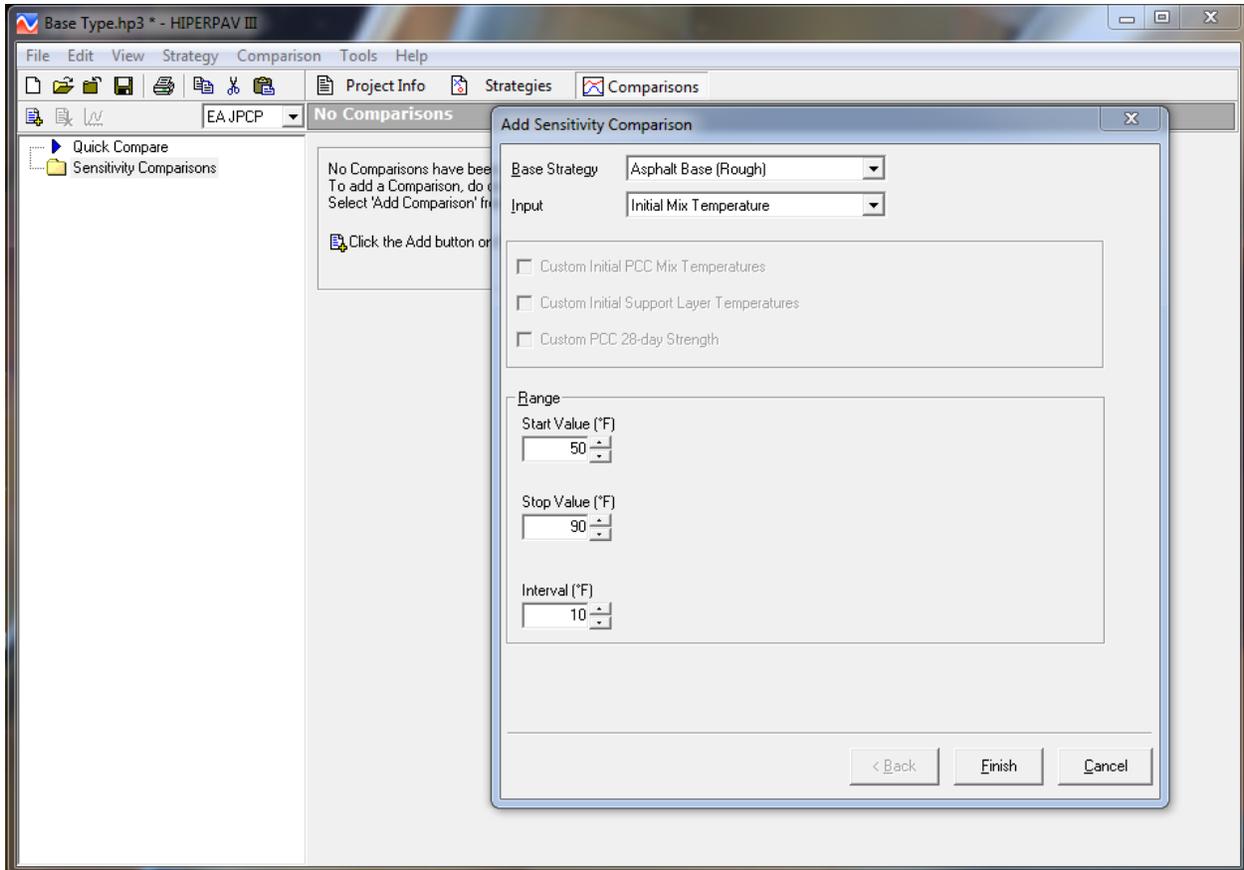


Figure 41. Screen Capture. Snapshot of the Add Sensitivity Comparison wizard.

Figure 42 presents the results from this sensitivity analysis in terms of stress-to-strength ratio. A Summary window shows the maximum stress-to-strength ratio for each analysis run in a bar chart as seen in figure 43. The bars are plotted in a color gradient from green (low cracking risk) to red (high cracking risk) to show the proximity to the critical stress-to-strength ratio of 100 percent (cracking risk threshold).

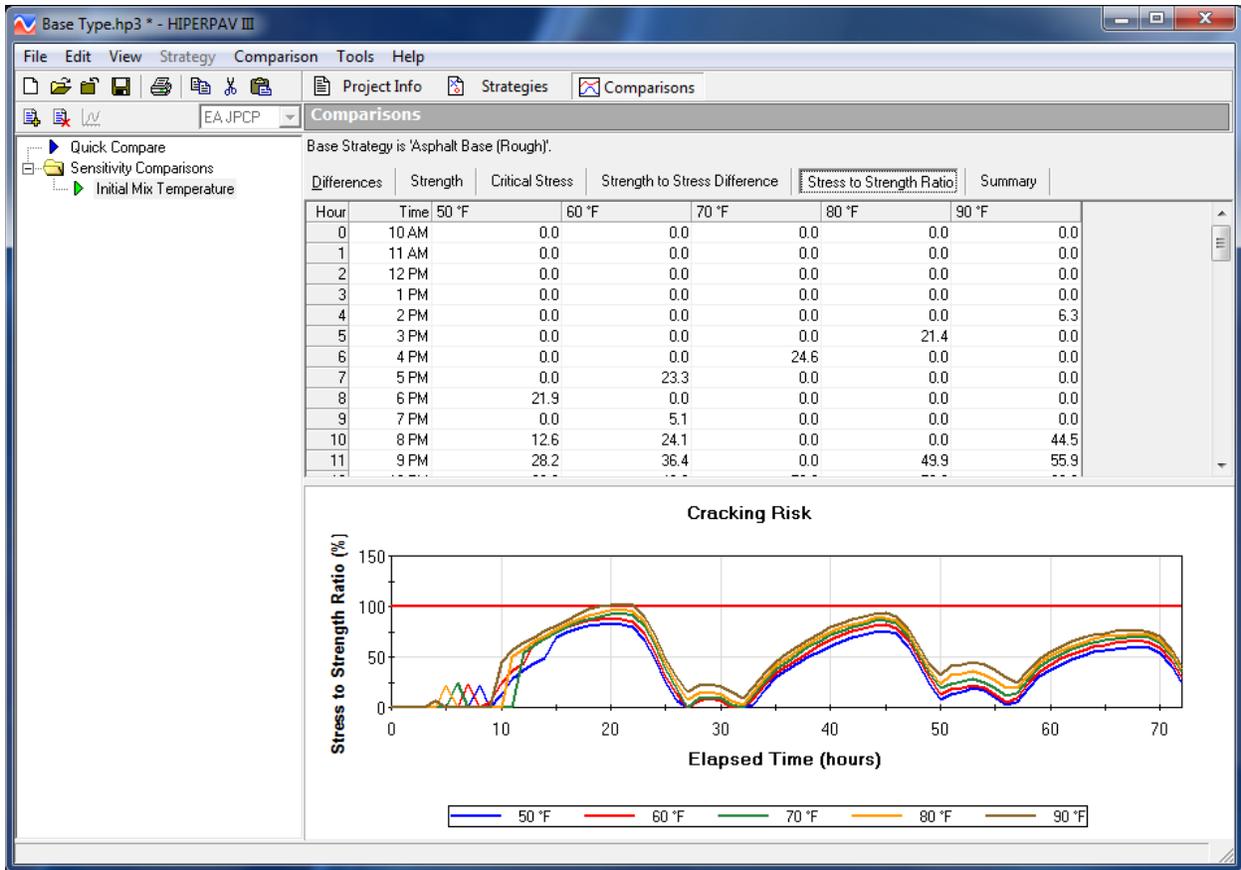


Figure 42. Screen Capture. Snapshot of Sensitivity Comparisons Stress-to-Strength ratio window.

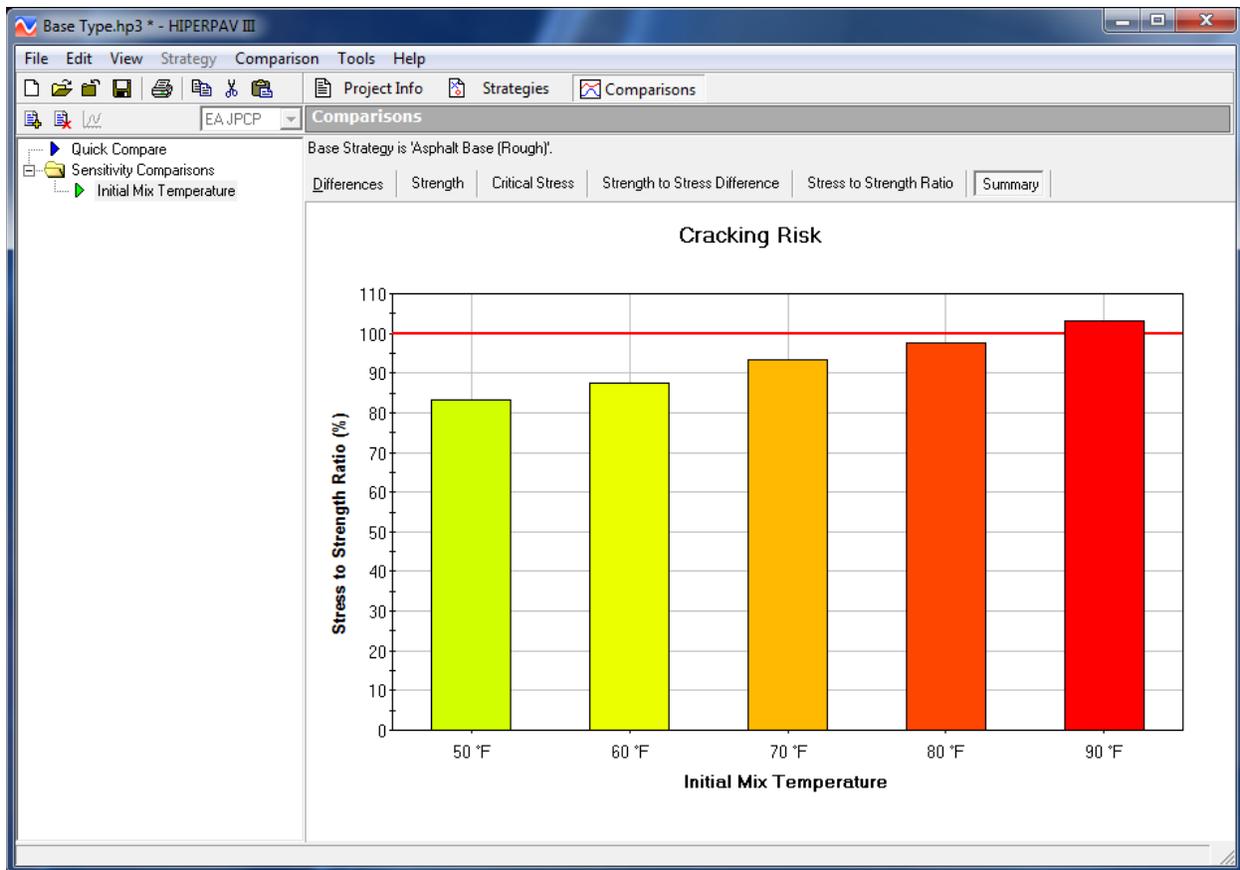


Figure 43. Screen Capture. Snapshot of the Sensitivity Comparison Summary window for PCC mix temperature.

Most often, users of previous versions 2.0 and 3.0 requested the ability to compare the effect of different times of construction without having to create individual strategies for each interval of time. The Sensitivity Comparisons tool gives the user that ability. The user identifies a base strategy, selects Construction Time as the variable to evaluate, and chooses a range from 1 to 6 hours.

For this sensitivity analysis, the user also has the option to use custom initial PCC mix and support layer temperatures for each analysis interval. If this information is not readily available, HIPERPAV® can estimate these temperatures based on current environmental conditions for each construction time if the user leaves the check boxes under each of these inputs unchecked.

HIPERPAV® calculates and generates charts and graphs accordingly. Similar to the previous example, the user can see in one snapshot the effect that time of construction has on stress-to-strength ratio. Figure 44 shows a summary of the stress-to-strength ratio for a time of construction sensitivity analysis. The user can quickly see that during some morning hours there is a higher probability of exceeding the cracking risk line.

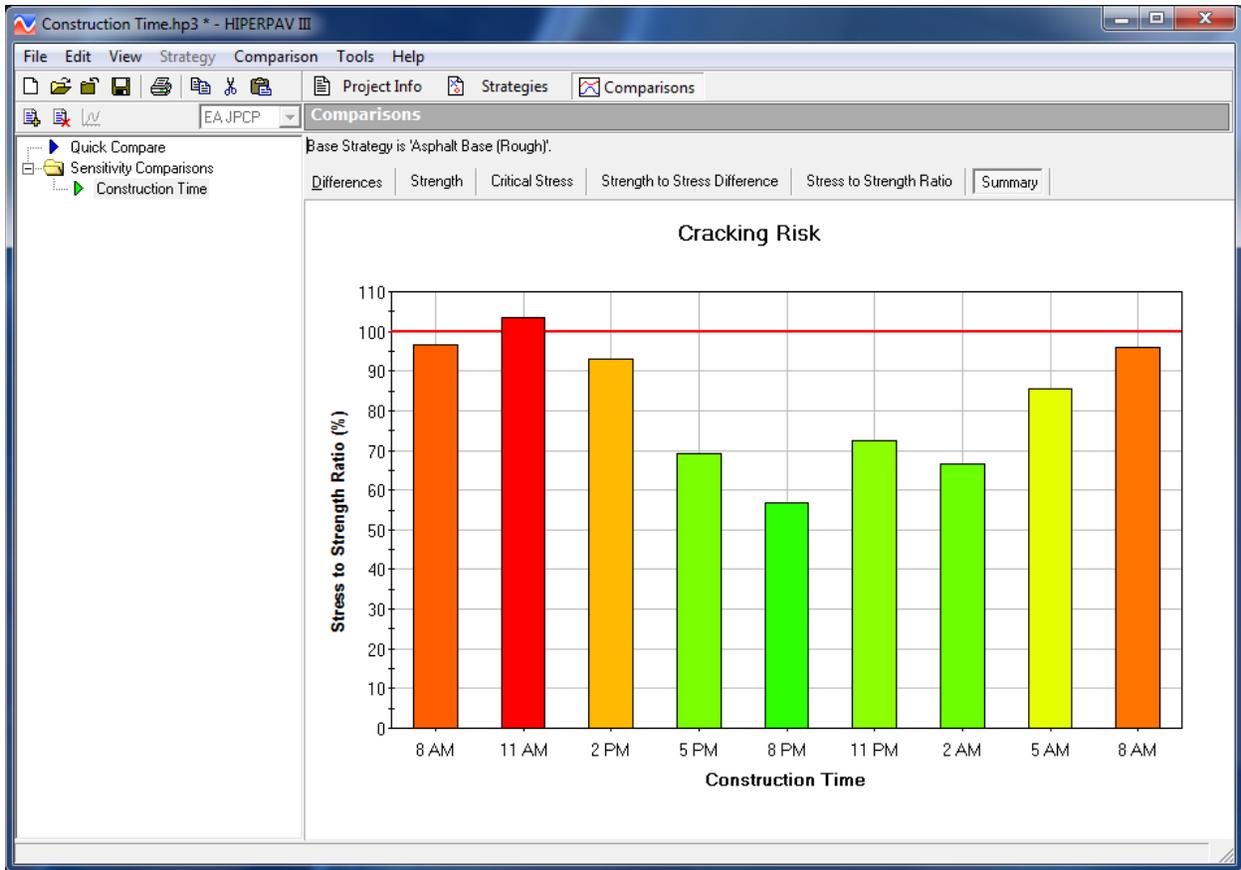


Figure 44. Screen Capture. Snapshot of the Sensitivity Comparisons Summary window for construction time.

CHAPTER 3. LONG-TERM JPCP PROJECTS

The main focus of the software is on the early-age behavior of JPCP. The long-term performance module should be used to further optimize early-age pavement design, materials selection, and construction procedures. The long-term JPCP project type analysis is intended to be a tool for examining relative, rather than absolute, performance based on early-age factors. This means that HIPERPAV® is intended to be used for evaluating and comparing the long-term performance analysis of one early-age strategy to another. In this way, the long-term module can reinforce good paving practices. It must not be used for pavement (structural) design purposes.

In this chapter, the long-term comparative analysis of early-age strategies is demonstrated. The user should be familiar with the early-age JPCP analysis windows before proceeding with this chapter. The long-term project type analysis includes Project Info and Strategies sections. In each section, project-specific data are entered into input windows that are categorized and listed in menu format down the left sidebar of every window.

PROJECT INFORMATION

Once the user selects the Long-Term JPCP option in the New Project selection window (see figure 1), the Project Information input window appears. Project Information is one of three categories for which there are input windows. The same input categories listed for early-age JPCP are listed for long-term JPCP. This is because the process for analyzing early-age strategies must be completed before long-term analyses can be run. Refer to chapter 2 for a step-by-step explanation of how to navigate the early-age section.

STRATEGIES

After navigating through the Project Info tab, two early-age JPCP strategies with default inputs are automatically generated by the software. The user should modify the inputs for the specific situation. Once the inputs for all of the early-age strategies have been entered and both strategies have been analyzed, long-term JPCP strategies can be created by selecting “LT JPCP” under the strategy type drop-down menu (see figure 45). For more detail on how to navigate the Strategies module for early-age strategies, refer to the Strategies subsection later in this chapter.

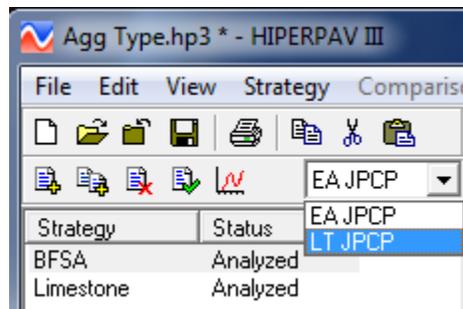


Figure 45. Screen Capture. Strategy type drop-down menu.

Notice that although two early-age strategies were analyzed, only one long-term strategy is generated automatically. Long-term JPCP strategies represent a single evaluation in which two early-age strategies are compared. Therefore, for every long-term strategy, two early-age

strategies are required. This allows the user to see how early-age factors affect long-term pavement performance.

The long-term JPCP Strategies module includes four categories of input windows and one analysis window. Input categories include Strategy Information, Performance Parameters, Joint Design, and Traffic Loading (see figure 46).

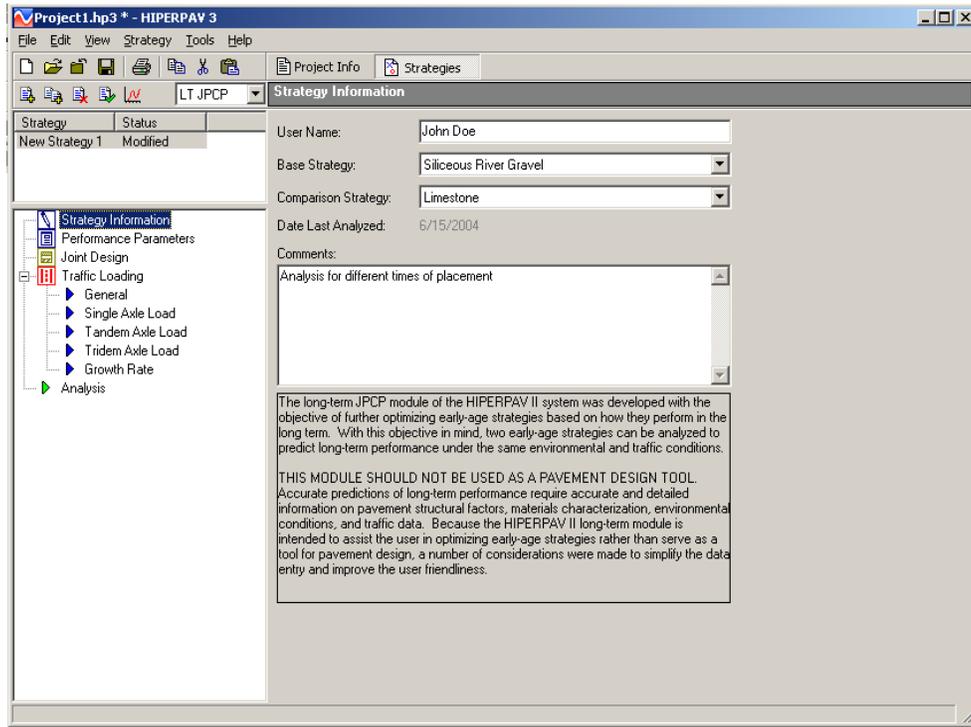


Figure 46. Screen Capture. Strategy Information for long-term JPCP analysis.

Strategy Information

The Strategy Information category consists of only one input window. In this window the user must identify which early-age strategy is the “Base Strategy” and which is the “Comparison Strategy”. Fields for user name and comments also are provided. After the long-term strategy is run, the date of analysis will appear in this window.

Performance Parameters

The Performance Parameters category also consists of only one input window. The user is able to enter the long-term analysis period, the reliability level, and the initial roughness index (IRI) (figure 47). An option is also provided to assess the effect of built-in curling. Built-in curling is a term used to describe the curling state that develops at set and that later influences the curled shape of the slab as the thermal gradient is subsequently modified by the hydration process and climatic conditions. HIPERPAV® considers the following two slab curling conditions:

- Consider built-in curling effect checkbox—unchecked: Curling stresses are computed for thermal gradient at time of loading only (assumes flat slab when thermal gradient is zero).
- Consider built-in curling effect checkbox—checked: Curling stresses are computed for thermal gradient at time of loading plus built-in curling present at PCC set time.

Because built-in curling relaxes with time, neither of the conditions described above is actually correct, but it is believed that the actual condition will lie between these two. During the model validation, it was observed that, depending on the thermal gradient built-in at set (positive or negative), considering built-in curling would show greater potential of cracking in some instances, and for others, not considering built-in curling would be more critical. Therefore, this option was left in the user’s control. The most critical case can be identified by running long-term strategies for both built-in curling and no built-in curling conditions at different times of placement. Long-term relaxation effects are difficult to assess at present, due to limitations of available models. In the future, these limitations may be overcome with the development of more sophisticated built-in curling models.

In addition to the above inputs, the user can set the maximum allowable joint faulting, transverse cracking, longitudinal cracking, IRI, and serviceability in this input window. These set limits are compared with the analysis results in the Long-Term Analysis window. If the analysis has predicted a level of distress that the user denotes as “terminating” (beyond the predefined distress threshold), HIPERPAV® reports it as the end of the service life for that analysis. However, the analysis continues until the analysis period is completed.

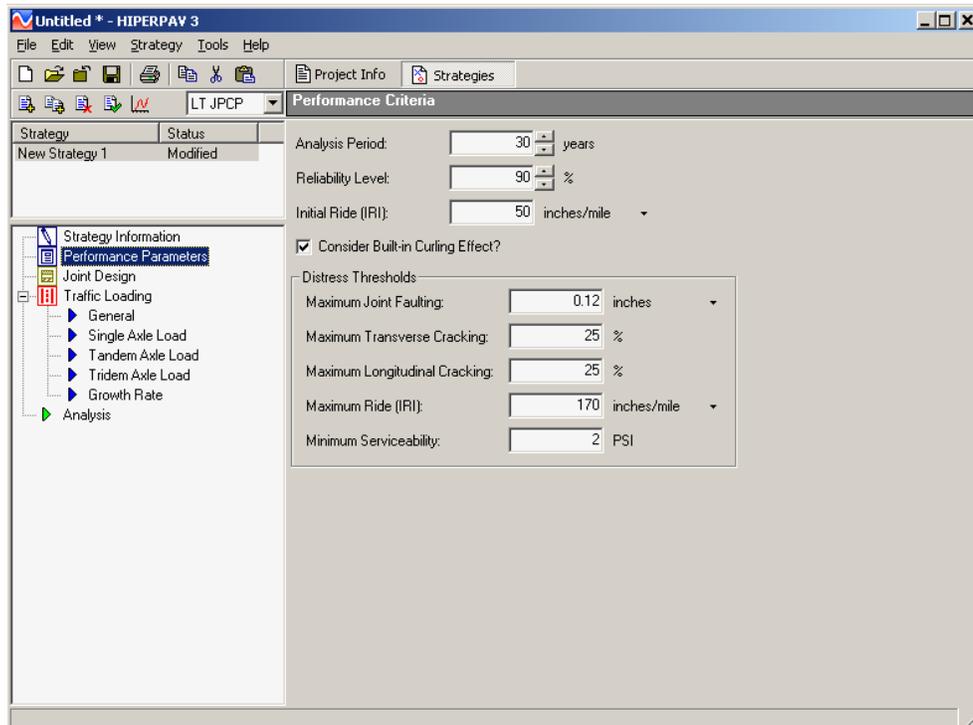


Figure 47. Screen Capture. Performance Parameters input window for long-term JPCP analysis.

Joint Design

The Joint Design category's single input window allows the user to select the type of load transfer device to consider in the analysis (i.e., dowels, tie bars, both, or none). Dowels reinforce the transverse joint, while tie bars reinforce the longitudinal joint (figure 48).

Users should note that dowel bar inputs for early-age analysis strategies do not apply to the long-term analysis. If dowels are selected as the load-transfer device in the long-term analysis, then for both the early-age base and early-age comparison strategies, dowels are used in the analysis, whether they were included as part of the early-age strategies' analyses or not.

The user can select from no transfer devices, only dowels, only tie-bars, or both dowels and tie bars. If dowels are selected, dowel spacing and length are required entries in addition to dowel size and modulus. If tie bars are selected, their size and spacing must be entered. The transverse sawcut depth is also entered as part of the joint design inputs.

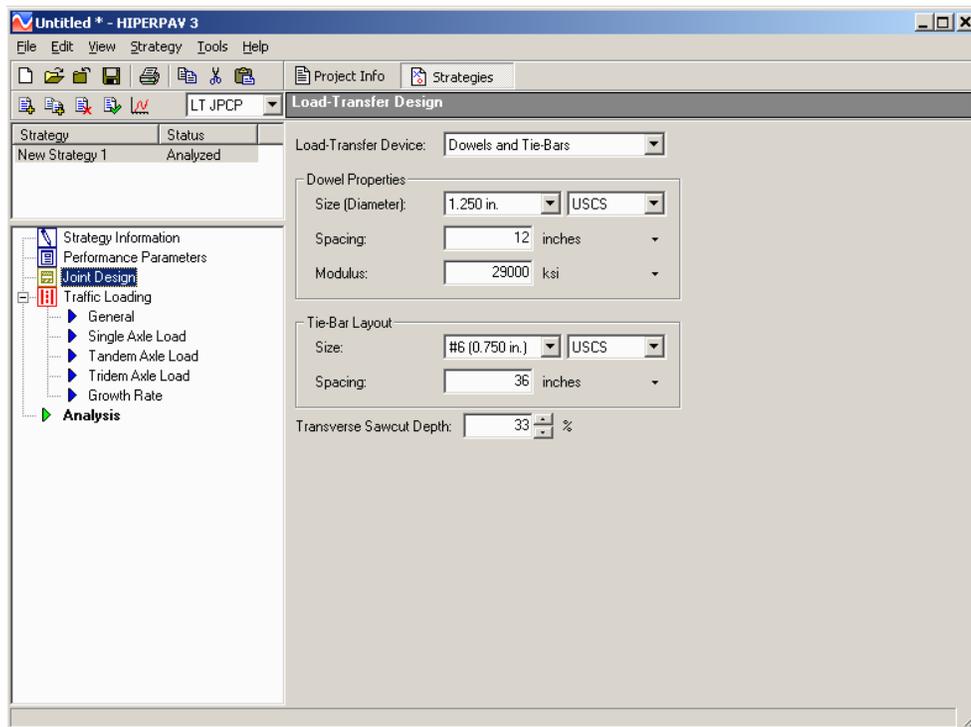


Figure 48. Screen Capture. Load-Transfer Design input window for long-term JPCP analysis.

Traffic Inputs

Traffic loading inputs must be included in the long-term analysis. Five input windows are provided for this category: General, Single Axle, Tandem Axle, Tridem Axle, and Growth Rate.

General

In the General window (figure 49), the mean truck tire pressure is required. The user also chooses to either estimate or define the traffic load spectra. If estimated, default traffic load

spectra (generated by HIPERPAV® (versions superseding software version 2.0) based on typical averages of rural and urban highway traffic) are used as inputs in the following three input windows. If the user-defined option is selected, the user can enter specific single axle, tandem axle, or tridem axle load values in the cells for traffic loading in their respective windows.

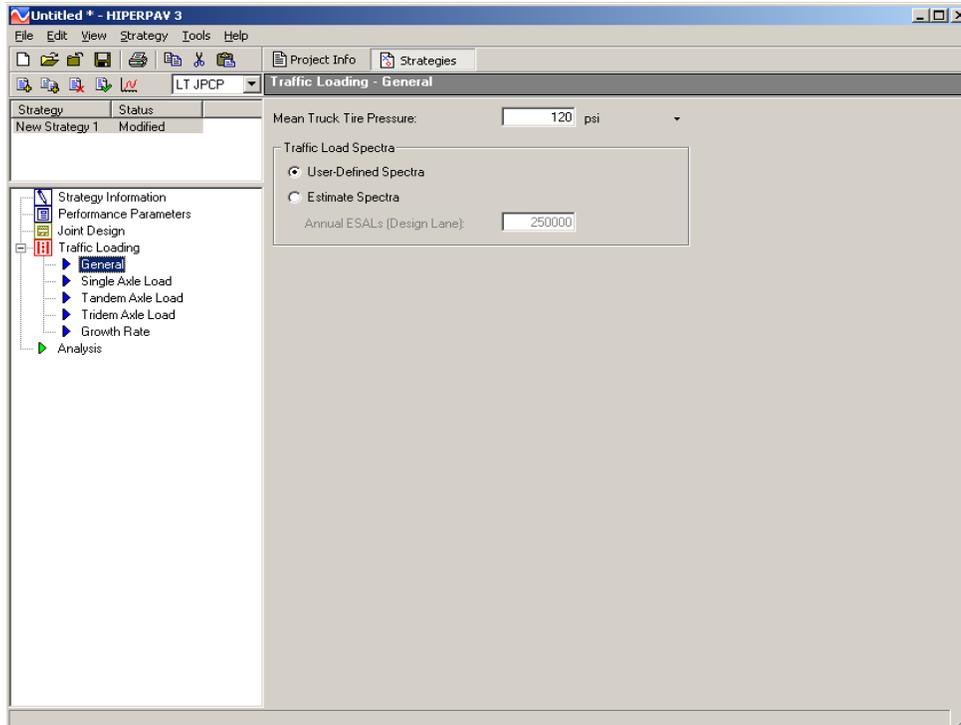


Figure 49. Screen Capture. General Traffic Loading window for long-term JPCP analysis.

Axle Load

If the user manually enters the load spectra information, these inputs are entered in the single axle load, the tandem axle load, and the tridem axle load windows (figure 50).

For each traffic load spectra category, the number of single tire and dual tire axle loads per year are entered against the axle load group. The single tire, dual tire, or total load spectra per axle type is shown on the plot, depending on the column selected. The total number of axles per axle load group is the sum of the respective single tire and dual tire values.

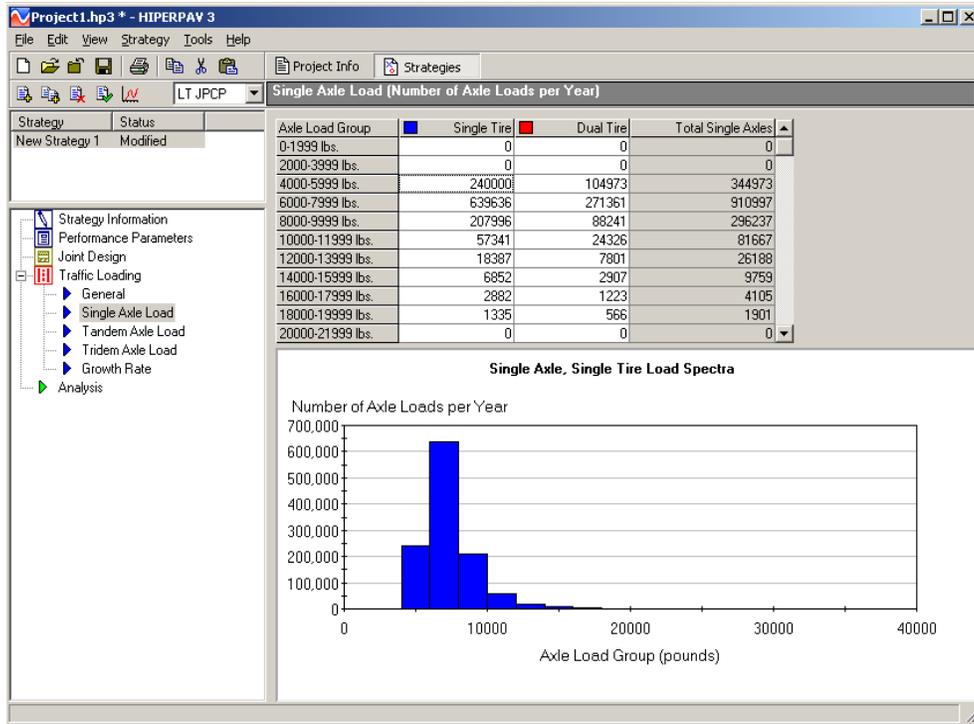


Figure 50. Screen Capture. Single Axle Load window for long-term JPCP analysis.

Traffic Growth Rate

The Growth Rate information is entered in the Growth Rate window (figure 51). The user can choose from three different growth functions to calculate the traffic growth rate: linear, exponential, or logistic. Depending on the function selected, the input requirements vary. For any function shown, the traffic loading is divided by the base-year traffic loading and plotted against time. Two plot methods may be selected: annual or cumulative.

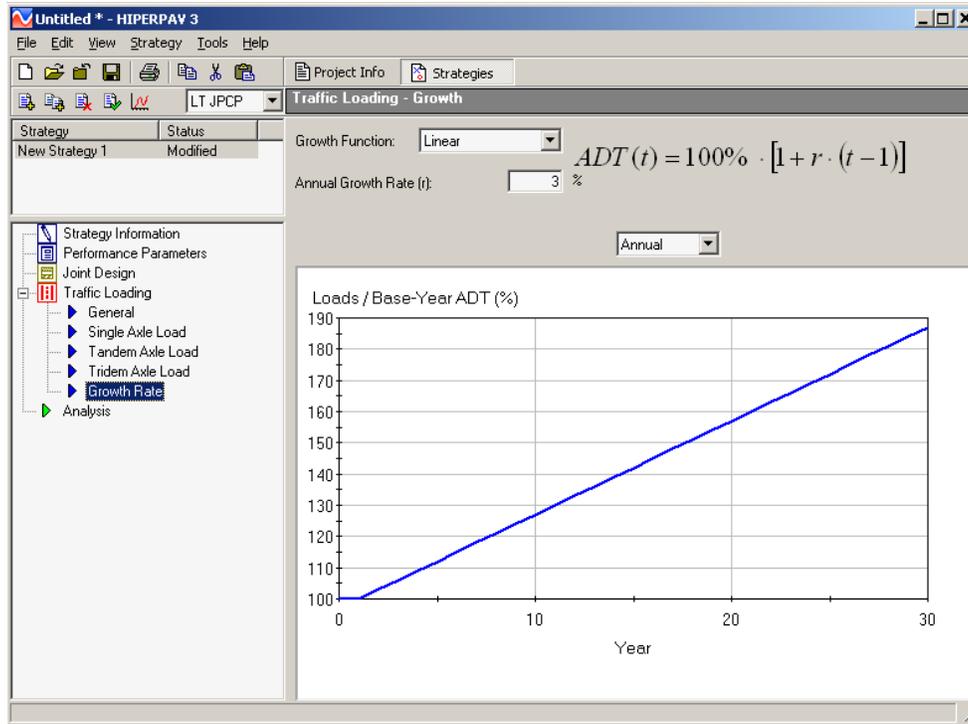


Figure 51. Screen Capture. Growth Rate input window for long-term JPCP analysis.

Long-Term Analysis

With the input assigned, the user should save the project file before performing a long-term JPCP analysis. After the analysis is run, a window appears showing the analysis status. The base strategy is analyzed first, followed by the comparison strategy (figure 52). For each strategy, several structural and functional distresses are predicted, including the following:

- Joint faulting.
- Transverse cracking.
- Longitudinal cracking.
- IRI.
- Serviceability.

After the analysis is complete, users can now select the type of distress to plot by selecting the distress drop-down menu (figure 53). Each distress type is plotted as a function of time. The distress magnitudes are presented in tabular format at the end of the prediction lifetime or at the time the threshold value is reached, whichever occurs first.

Using the data values plot method, absolute values of the distress are provided (see plot method drop-down in figure 54). If the change plot method is chosen, the change in predicted distresses between the base strategy and the comparison strategy is plotted.

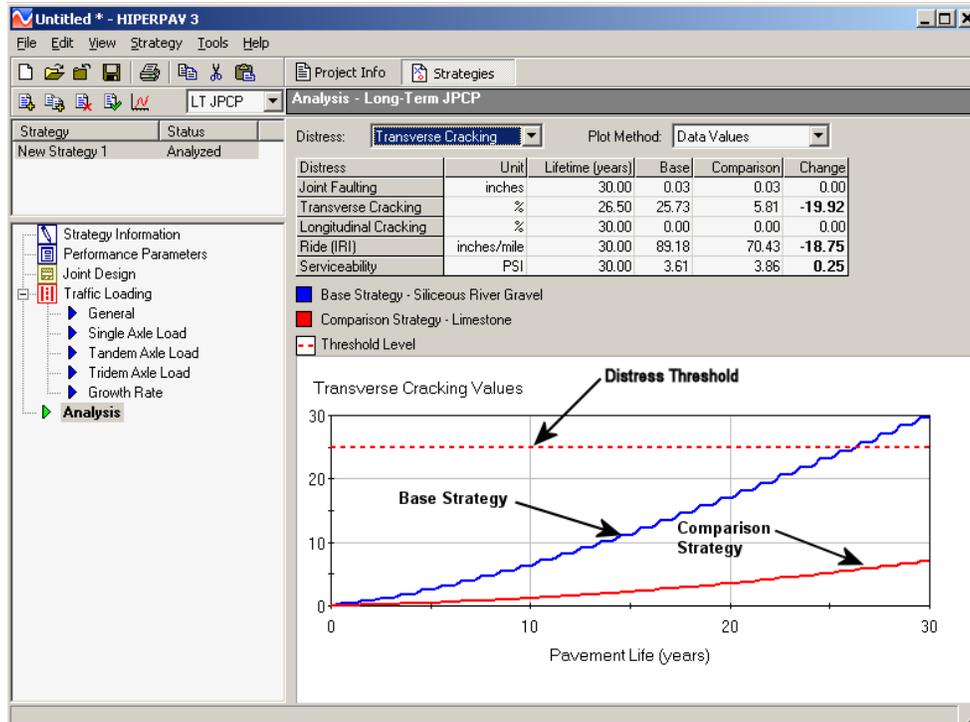


Figure 52. Screen Capture. Analysis window for long-term JPCP.

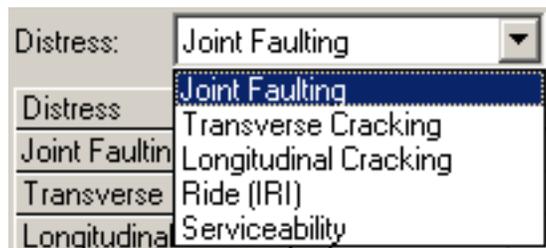


Figure 53. Drop-down menu for distress to plot.

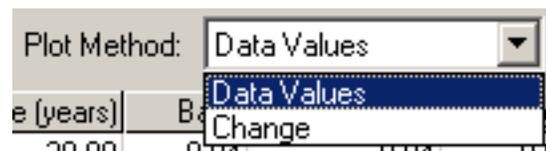


Figure 54. Screen Capture. Plot method drop-down menu.

Multiple Long-Term Comparative Strategies

When more than two early-age strategies are to be compared in the long-term module, the comparison is accomplished by creating additional strategies with the Strategy toolbar. Once the strategy is created, the additional strategies to compare are selected in the Strategy Information window, as previously described.

Early-Age and Long-Term JPCP Analysis—Sample Scenario

In this section, step-by-step instructions are provided to show the effect of aggregate selection on early-age thermal cracking potential and on long-term transverse cracking. The early-age inputs used for this exercise are presented in table 1. Input values in bold represent the inputs that are different for these two early-age strategies.

Table 1. Inputs for 11 a.m. and 7 p.m. times of placement strategies.

Input Category	Input Window	Input Value
Project Information	Geography	Austin, TX
	Monthly Weather Data	Estimate Monthly Data from Location
Strategy Information	Reliability Level	90 percent
Design	Geometry	New Slab Thickness = 250 mm New Slab Width = 3.65 m Transverse Joint Spacing = 4.5 m
	Dowels Analysis	Disabled
	Slab Support	Material Type = HMA (rough) k -value = 55 MPa/m Subbase Thickness = 15 cm Subbase Modulus = 3500 MPa Axial Restraint = Estimate from Material Type
Materials and Mix Design	Cement	ASTM Cement Type Classification = Cement Type I Blaine Fineness Index = Estimate from Cement Type
	PCC Mix	Aggregate Type = Siliceous River Gravel (Baseline Strategy) Limestone (Comparison Strategy) Admixtures = None Fly Ash Class = Class F (CaO \leq 7.0 percent) Coarse Aggregate = 1100 kg/m ³ Fine Aggregate = 800 kg/m ³ Water = 128 kg/m ³ Cement = 284 kg/m ³ Fly Ash = 60 kg/m ³ GGBFS = 0 kg/m ³ Silica Fume = 0 kg/m ³
	PCC Properties	28-Day Splitting Tensile Strength = 3.2 MPa PCC 28-Day Modulus = 35,000 MPa PCC Ultimate Drying Shrinkage = Estimate from Mix PCC CTE = Estimate from Aggregate Type
	Maturity Data	Default Strength Gain
Construction	Construction	Initial PCC Mix Temperature = 32.2 °C Initial Support Layer Temperature = 31.7 °C Curing Method = Single Coat Curing Liquid Compound Age Curing Applied = 0 Hours Sawcutting: Saw at Optimum Time Skip Sawcutting: Not Used Strength for Opening to Traffic = Not Relevant for This Analysis
Climate	Climate	Construction Date: July 18, 2002 (year irrelevant for analysis because temperatures are historical averages) Construction Time: 11:00 a.m. Temperature, Windspeed, Relative Humidity, and Cloud Cover = Estimate from Location

HMA = Hot mix asphalt

GGBFS = Ground-granulated blast-furnace slag

PCC = Portland cement concrete

CTE = Coefficient of thermal expansion

To perform this analysis, a new long-term JPCP analysis is selected in the New Project selection window (see figure 1). The first step is to select the project location in the Geography input window. For details on how to do this, see the explanation presented in the Geography subsection of chapter 2 of this manual. If not yet chosen, use the icons in the Geography toolbar shown in figure 55 to select Austin, TX, in the U.S. map.



Figure 55. Screen Capture. Icons on Geography toolbar to select Austin, TX.

Next, select “Estimate Monthly Data from Location” in the Monthly Weather data window (see figure 5).

To enter the early-age inputs for the siliceous river gravel strategy, select the Strategies tab. To rename this strategy “Siliceous River Gravel,” right-click on it and select “Rename” or select “Rename” from the Strategy option on the top menu. Under “Strategy Information” the reliability level is set to 90 percent. In the same way, all other inputs shown in Table 1 are entered under the design, materials and mix design, construction, and climate input windows. For this exercise, data for temperature, wind speed, relative humidity, and cloud cover are set to the default values estimated for that location.

After all the above inputs are entered, the user can perform the analysis by clicking on the  analysis icon of the Strategy toolbar or by selecting “Run Analysis” from the Strategy option on the top menu. The results from this analysis are presented in figure 56. The results show a high risk of thermal cracking for the siliceous river gravel strategy.

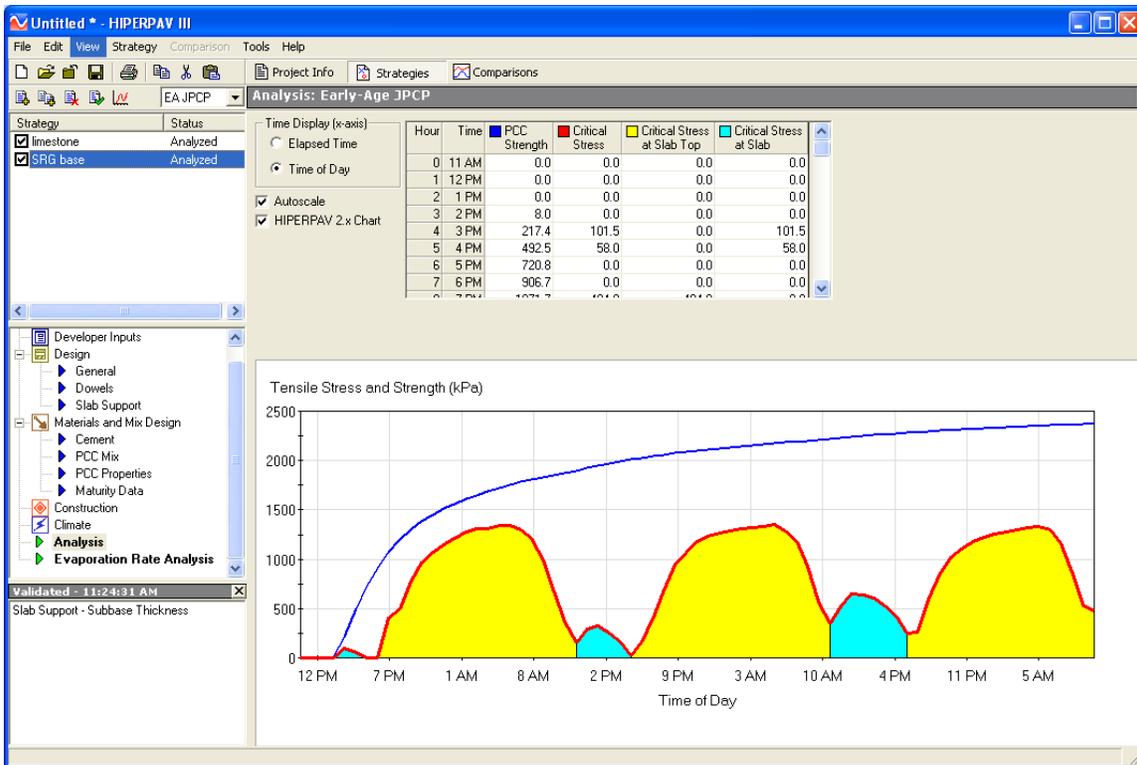


Figure 56. Screen Capture. Early-Age Analysis window for the siliceous river gravel strategy.

To proceed with the second strategy (using limestone coarse aggregate), the user may either enter the information on a new strategy or create a copy of the siliceous river gravel strategy. The latter is recommended because all previously entered data that are identical for the second strategy will be automatically copied to the second strategy. To do this, select the siliceous river gravel strategy and click the  copy strategy icon. “Copy of Siliceous River Gravel Strategy” appears under the strategy list. To rename this strategy “Limestone,” right-click it and select “Rename” or select “Rename” from the Strategy option on the top menu.

For the limestone strategy, change the aggregate type to limestone in the aggregate type dropdown menu under the PCC Mix input window (see figure 17). After completing the inputs for the limestone strategy, perform the analysis by clicking the  analysis icon of the Strategy toolbar. The result from this analysis is presented in figure 57.

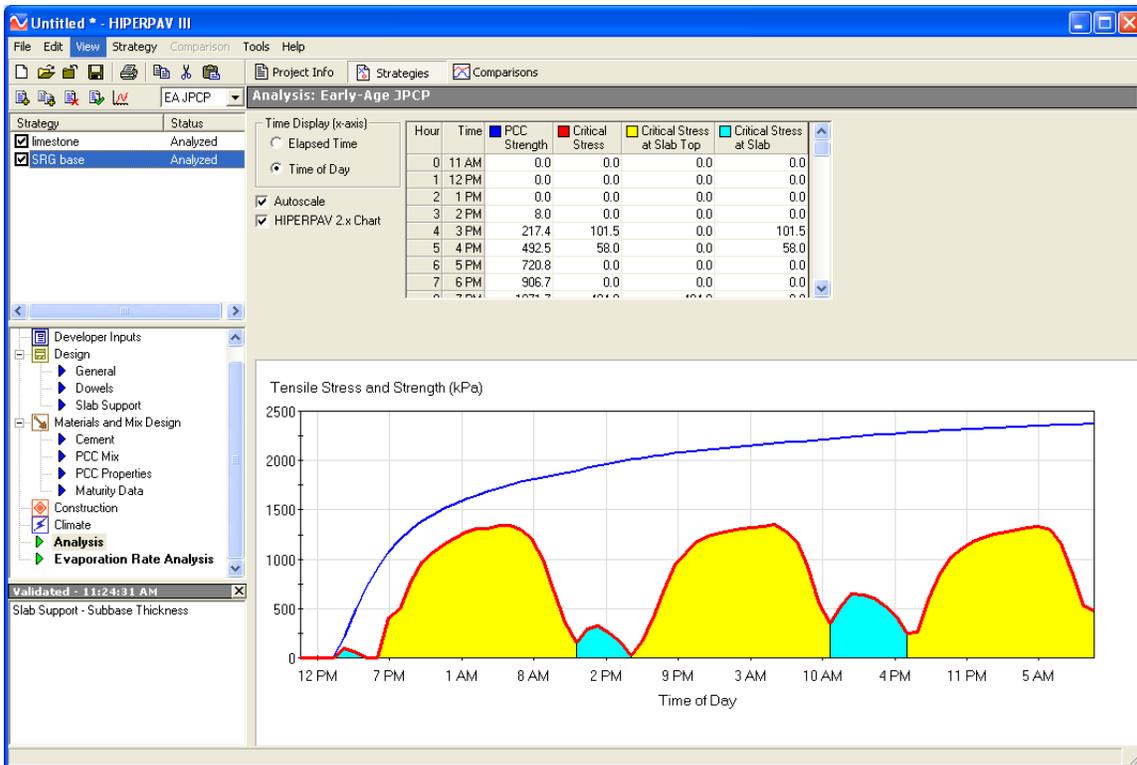


Figure 57. Screen Capture. Early-Age Analysis window for siliceous river gravel strategy.

After the two early-age strategies have been analyzed, select “LT JPCP” under the analysis type drop-down (see figure 58). Then, under “Strategy Information” select the siliceous river gravel early-age strategy as the base strategy and the limestone early-age strategy as the comparison strategy (see figure 59). Complete entries in the remaining input windows with the information provided in table 2.

Table 2. Long-term inputs for aggregate selection sample scenario.

Input Category	Input Window	Input Value
1. Strategy Information	Strategy Information	Base Strategy: Siliceous River Gravel Comparison Strategy: Limestone
Performance Parameters	Performance Parameters	Analysis Period: 30 Years Reliability Level: 90 percent Initial Ride: 0.8 m/km Consider Built-in Curling Effect: Yes Distress Thresholds: Maximum Joint Faulting: 3 mm Maximum Transverse Cracking: 25 percent Maximum Longitudinal Cracking: 25 percent Maximum Ride (IRI): 2.7 m/km Minimum Serviceability: 2.0
Joint Design	Joint Design	Load Transfer Devices: Dowels and Tie-Bars Dowel Properties: Size (Diameter): 32 mm Spacing: 300 mm Modulus: 200,000 MPa Tie-Bar Layout: Size: 19.1 mm Spacing: 0.9 m Transverse Sawcut Depth: 33 percent of Thickness
Traffic Loading	General	Mean Truck Tire Pressure: 0.84 MPa Traffic Load Spectra: Estimate Spectra from ESAL Annual ESAL (Design Lane): 250,000
	Single Axle Load	Estimate from ESAL
	Tandem Axle Load	Estimate from ESAL
	Tridem Axle Load	Estimate from ESAL
	Growth Rate	Growth Function: Linear Annual Growth Rate: 3 percent Plot Method: Annual

ESAL = Equivalent Single Axle Load

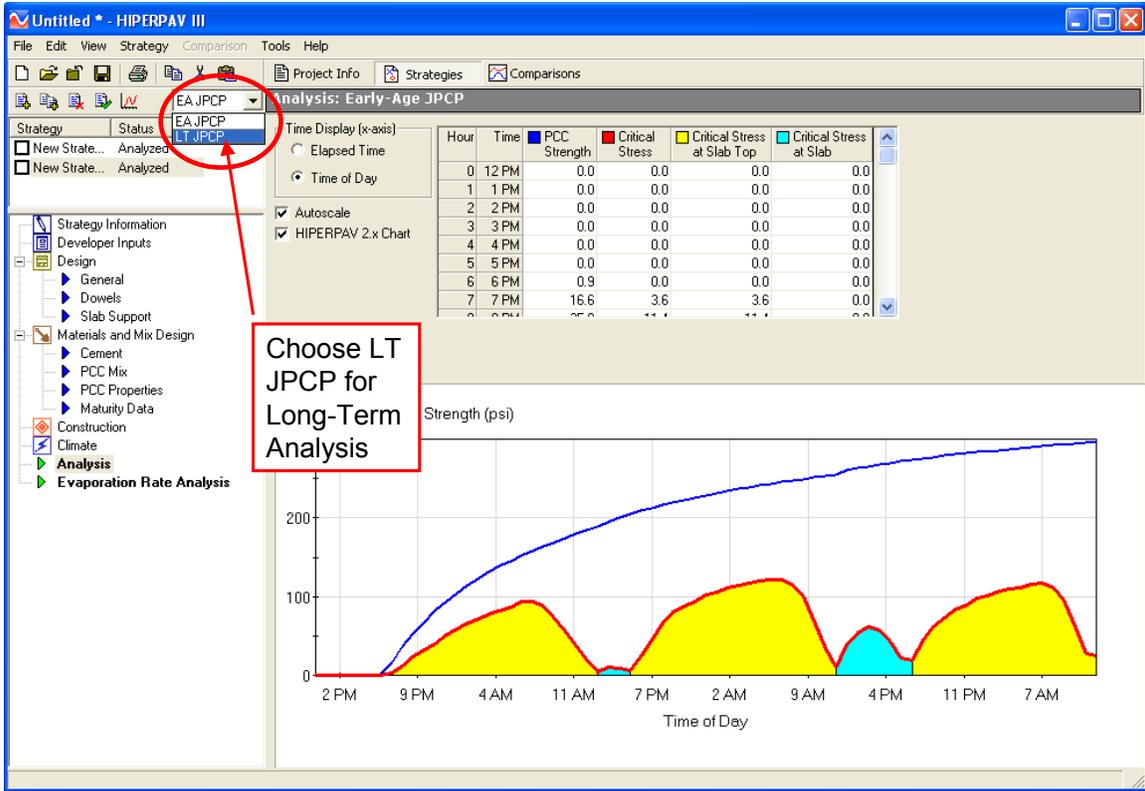


Figure 58. Screen Capture. Drop-down menu with “LT JPCP” selected.

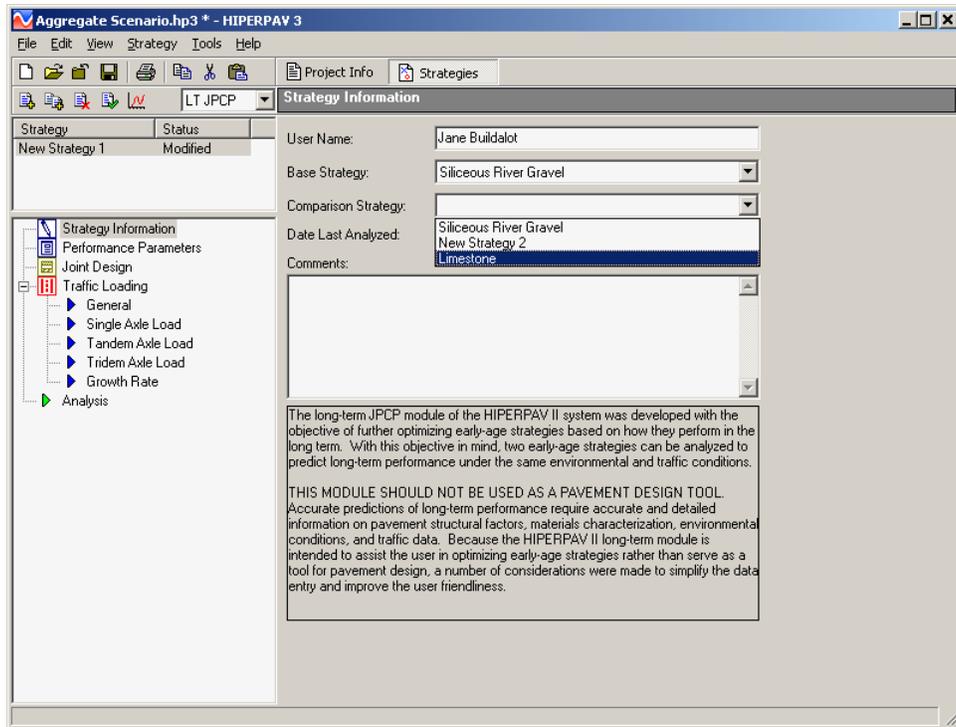


Figure 59. Screen Capture. Selection of early-age strategies to compare.

After all the inputs have been entered, the user may perform the analysis by clicking the  analysis icon of the Strategy toolbar or by selecting “Run Analysis” from the Strategy option on the top menu. The joint faulting analysis is presented after the analysis is run. Transverse cracking may be selected from the distress to plot drop-down menu (figure 53). The transverse cracking results for the siliceous river gravel and limestone early-age strategies are shown in figure 60. The strategy with siliceous river gravel coarse aggregate shows a greater development of transverse cracking compared with the strategy with limestone coarse aggregate. From this analysis, selecting the limestone coarse aggregate source with a lower CTE appears to result in better performance, both in the early age and in the long term.

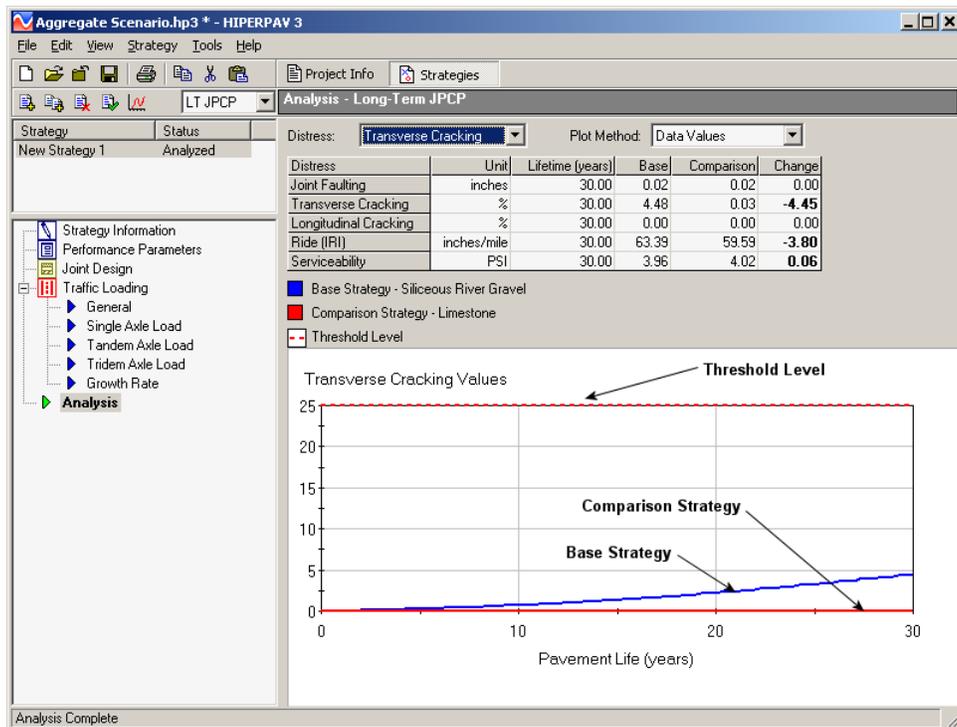


Figure 60. Screen Capture. Long-term strategy transverse cracking results.

CHAPTER 4. EARLY-AGE CRCP ANALYSIS

In this chapter, the analysis for an early-age CRCP project type is demonstrated.

After the user selects the Early-Age CRCP option in the New Project selection window (figure 1), the software creates an early-age CRCP strategy with default inputs that the user can modify with information for the specific situation. The input windows are similar to those required for the early-age JPCP analysis, but with some differences. There are only two sections, or tabs for which input windows are categorized: Project Info and Strategies.

After inputs are entered in the Project Information window, one or more strategies for that specific location can be created for analysis under the strategies section.

PROJECT INFO

There are two categories of input windows under the Project Info tab: Project Information and Geography. These two categories are the same as those for Early-Age JPCP project types. For details on how to enter job-specific data for these categories, refer to the Project Information and Geography subsections of chapter 2 of this manual.

STRATEGIES

Like the Strategies tab for Early-Age JPCP project types, Early-Age CRCP strategies are created using a toolbar of icons. For information on how to use the Strategy toolbar to create, add, or delete strategies, see the Strategy Toolbar subsection of chapter 2 of this manual.

The CRCP Strategies section contains the following categories of input windows:

- Strategy Information.
- Design.
- Materials and Mix Design.
- Construction.
- Environment.

Strategy Information

In the Strategy Information input window, the user can enter his or her name. After the strategy is run, the date of analysis will also appear in this window. A comment box is available for each strategy. This window is similar to the Strategy Information window for early-age JPCP analyses, although no reliability information is required (see the Strategy Information subsection of chapter 2 of this manual).

Design Inputs

The Design category includes input windows for geometry, steel design, and slab support information.

Geometry

The Geometry window (figure 61) provides fields to enter the slab thickness and slab width. The slab width that should be entered is the widest spacing between adjacent longitudinal joints.

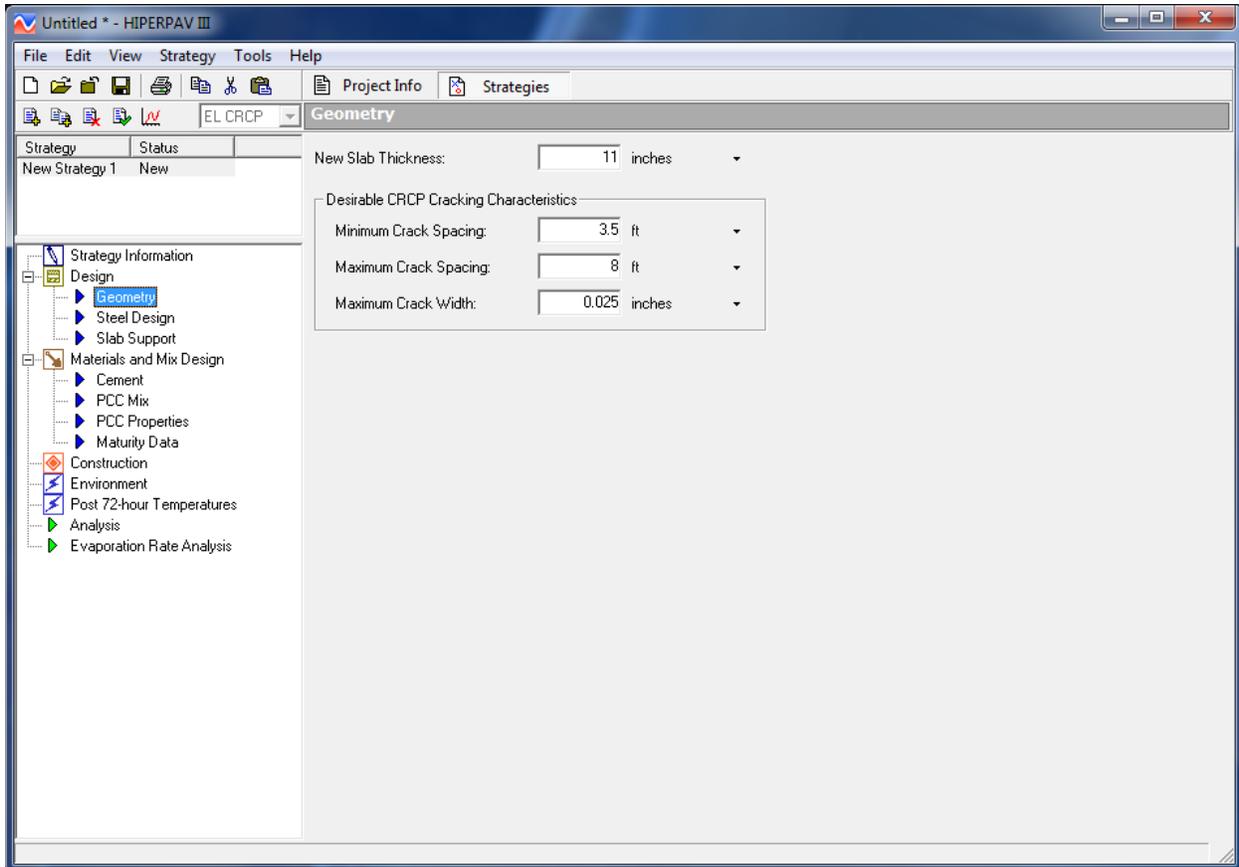


Figure 61. Screen Capture. Geometry input window for early-age CRCP analysis.

In addition, long-term desirable CRCP cracking characteristics (after 1 year), including minimum and maximum crack spacing and average crack width, can be entered; these will later be indicated by the dashed lines in the early-age CRCP analysis plot.

Steel Design

The longitudinal steel information can be entered in the Steel Design window (figure 64). Information about the longitudinal steel layout and steel properties is required. For the steel layout, the bar spacing and size are needed, as well as the number of steel mats. The steel properties needed are the steel yield strength, steel modulus, and CTE. HIPERPAV® then calculates, based on the input, the percent steel for the current slab thickness.

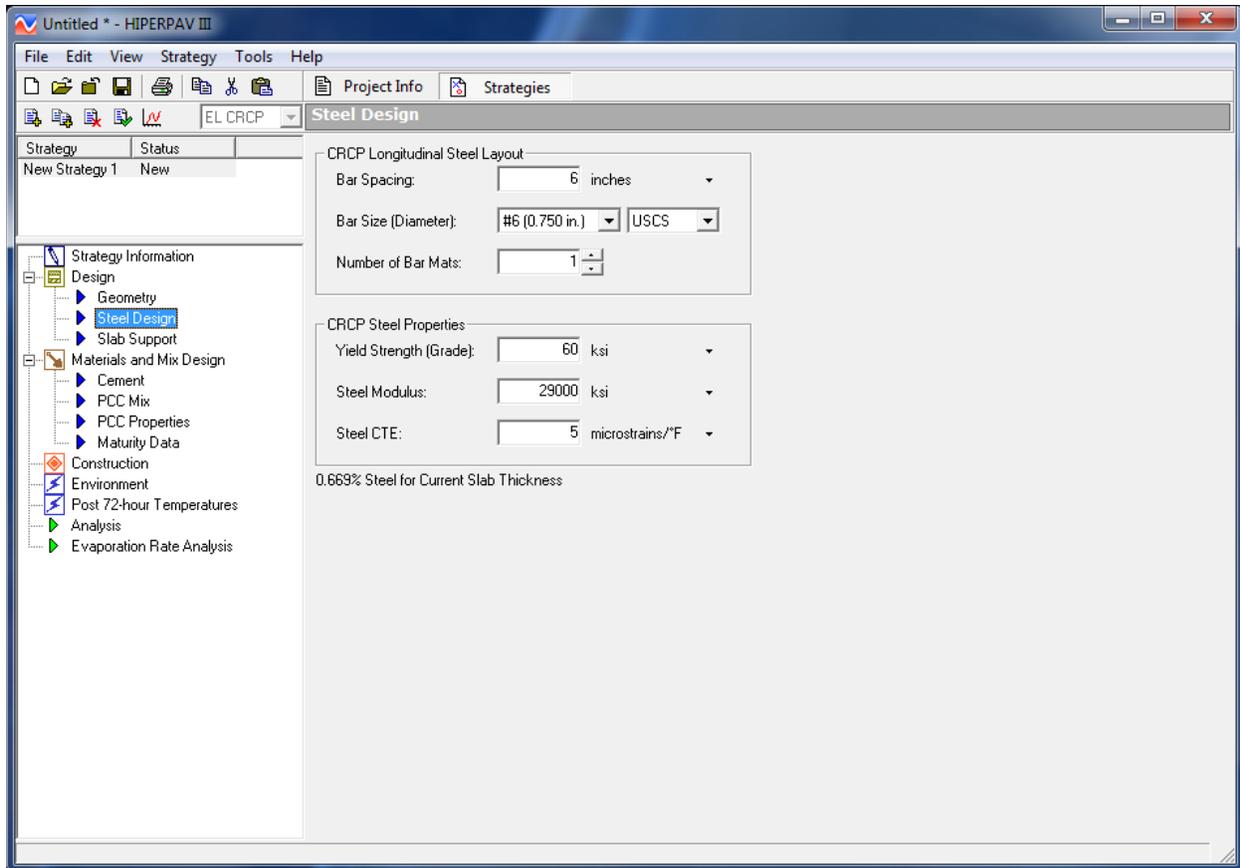


Figure 62. Screen Capture. Steel Design input window for early-age CRCP analysis.

Slab Support

This window is the same as the one found in the Early-Age project type. For information about this window, see the more detailed Slab Support subsection in chapter 2 of this manual.

Materials and Mix Design Inputs

The second input category is Materials and Mix Design. It is the same as the one found in the Early-Age JPCP project type; for details, see the subsection Materials and Mix Design Inputs in chapter 2 of this manual.

Construction

The third input category pertains to construction information. The Early-Age Construction window is shown in figure 63. In this window, the initial temperatures of the concrete mix and support layer are entered. Information on the curing method used (drop-down menu) is required along with the time of application, and if removable curing methods are selected, the age when curing is removed is also required.

In addition, if the effect of construction traffic is enabled, loading conditions are required. The user can assess the influence of construction traffic on the performance of the CRCP by entering

the days before the wheel load is applied, the wheel load, and the radius of the circular loaded area.

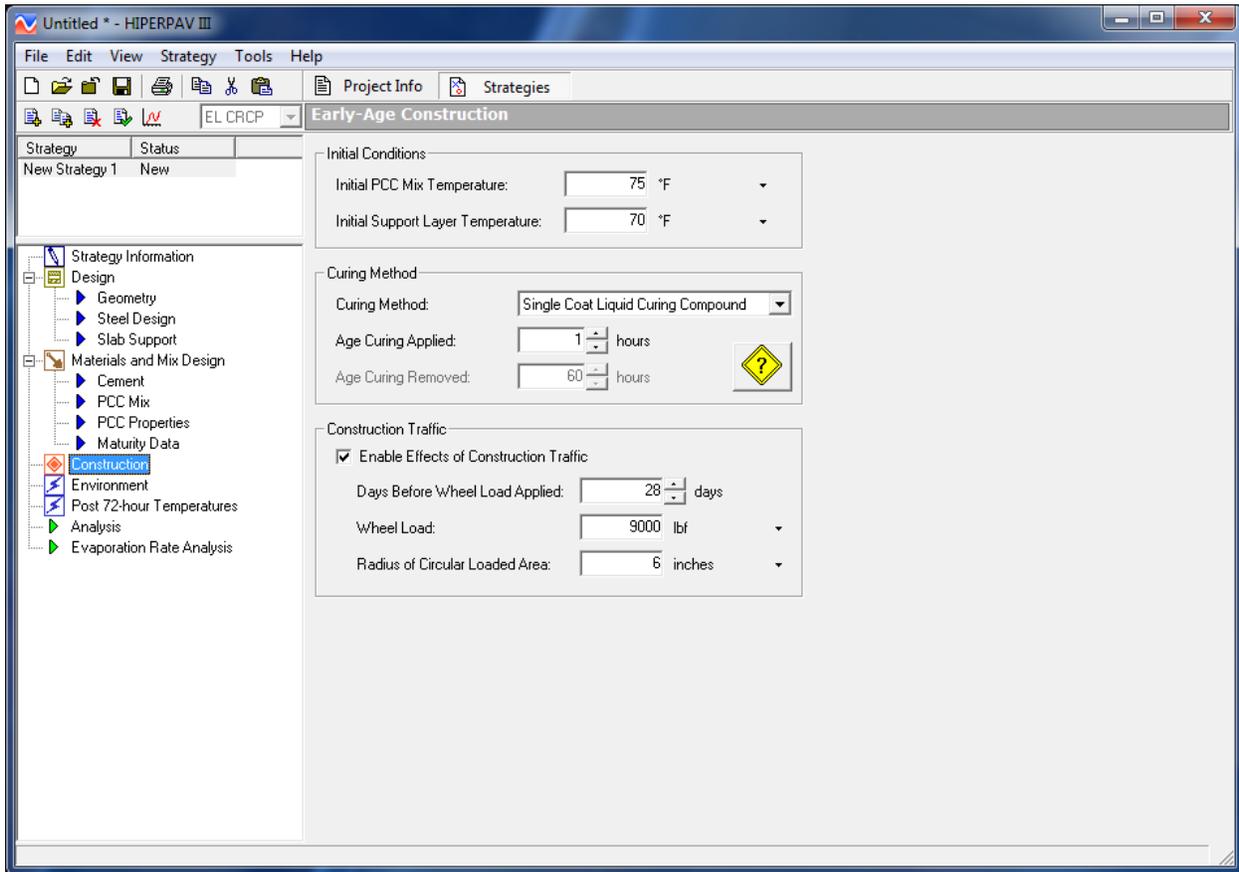


Figure 63. Screen Capture. Early-Age Construction input window for early-age CRCP analysis.

Environment

The input windows for the Environment category are the same as in the Early-Age JPCP input windows described in the Climate Inputs subsection of chapter 2 of this manual.

Post 72-Hour Temperatures

For the early-age CRCP analysis, the post 72-hour temperatures are required (figure 64). The critical analysis period corresponds to the time when construction traffic is applied. For this period, the minimum and maximum air temperatures are also required. In addition, after the critical analysis period, the date of the minimum temperature for the year is needed to estimate the pavement age for the largest temperature drop to which the pavement will be subjected. This date can be estimated by HIPERPAV® (versions 3.0, 3.2, and 3.3), or it can be defined by the user. Similarly, either HIPERPAV III® can estimate the minimum and maximum temperatures, or these can be input manually.

Early age for concrete includes the first 72 hours after construction for both JPCP and CRCP. Cracking in CRCP typically progresses until approximately 1 year after construction. After 1 year, cracking typically remains constant. The HIPERPAV III® analysis extends beyond early age, and up to 1 year (early life), to realistically assess the behavior of in-service CRCP.

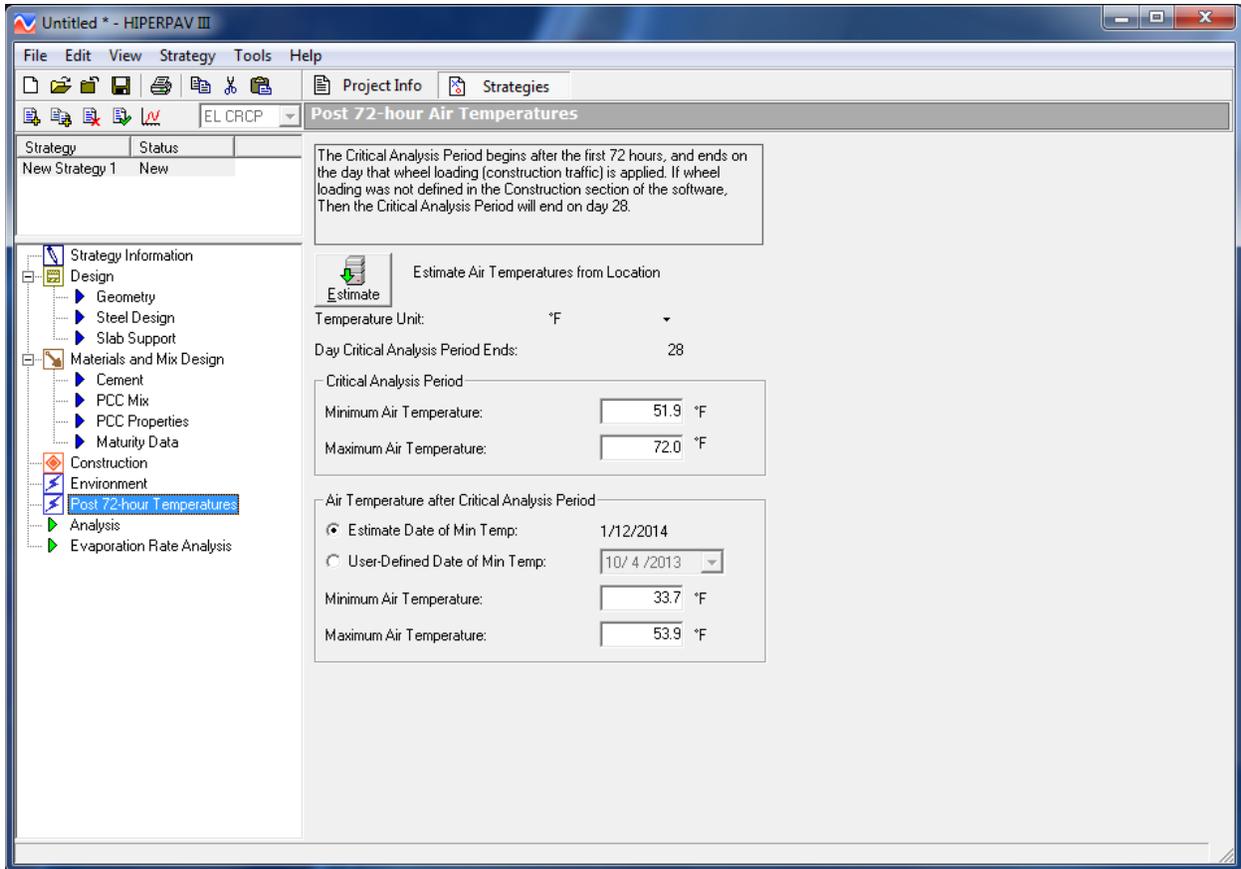


Figure 64. Screen Capture. Post 72-hour Air Temperatures input window for early-age CRCP analysis.

CRCP Analysis

With the inputs assigned, the user should save the file before performing an early-age CRCP analysis. The Analysis window for an early-age CRCP strategy is shown in figure 65. After the analysis is run, a window appears showing the analysis status. The analysis output, in tabular format, includes the average crack spacing and its standard deviation, the average crack width, the maximum steel stress, and the bond development length. Interpretation of the analysis is performed by comparing the cracking results with the thresholds previously set in “Desirable CRCP Cracking Characteristics” in the Geometry input window. These thresholds are also presented in the Analysis window for comparison.

The plot can either show the incremental or cumulative frequency versus crack spacing. Plots for the following three different points in time are provided: 1) at 3 days after construction; 2) for the critical analysis period when construction traffic is applied; and 3) at 1 year of age (“Time Period to Plot” drop-down menu in figure 66). The crack spacing frequency also is presented in

tabular format. The numerical value of crack spacing frequency can also be obtained by hovering the mouse over the point of interest in the plot. As shown in figure 67, a help window is provided to caution the user on the validation of the crack width model incorporated in HIPERPAV III®. This window also defines the analysis period used for CRCP behavior analyses.

Also, because more than one strategy can be analyzed with HIPERPAV III®, comparisons can be made between the analysis results more easily. It is possible to toggle between the Analysis windows by selecting one strategy and then the other one (for this, the user must have analyzed at least two strategies previously for comparison and toggled between them).

An analysis window for evaporation rate is also provided. The Evaporation Rate Analysis is the same as for the early-age JPCP (see the Evaporation Rate Analysis subsection of chapter 2 of this manual).

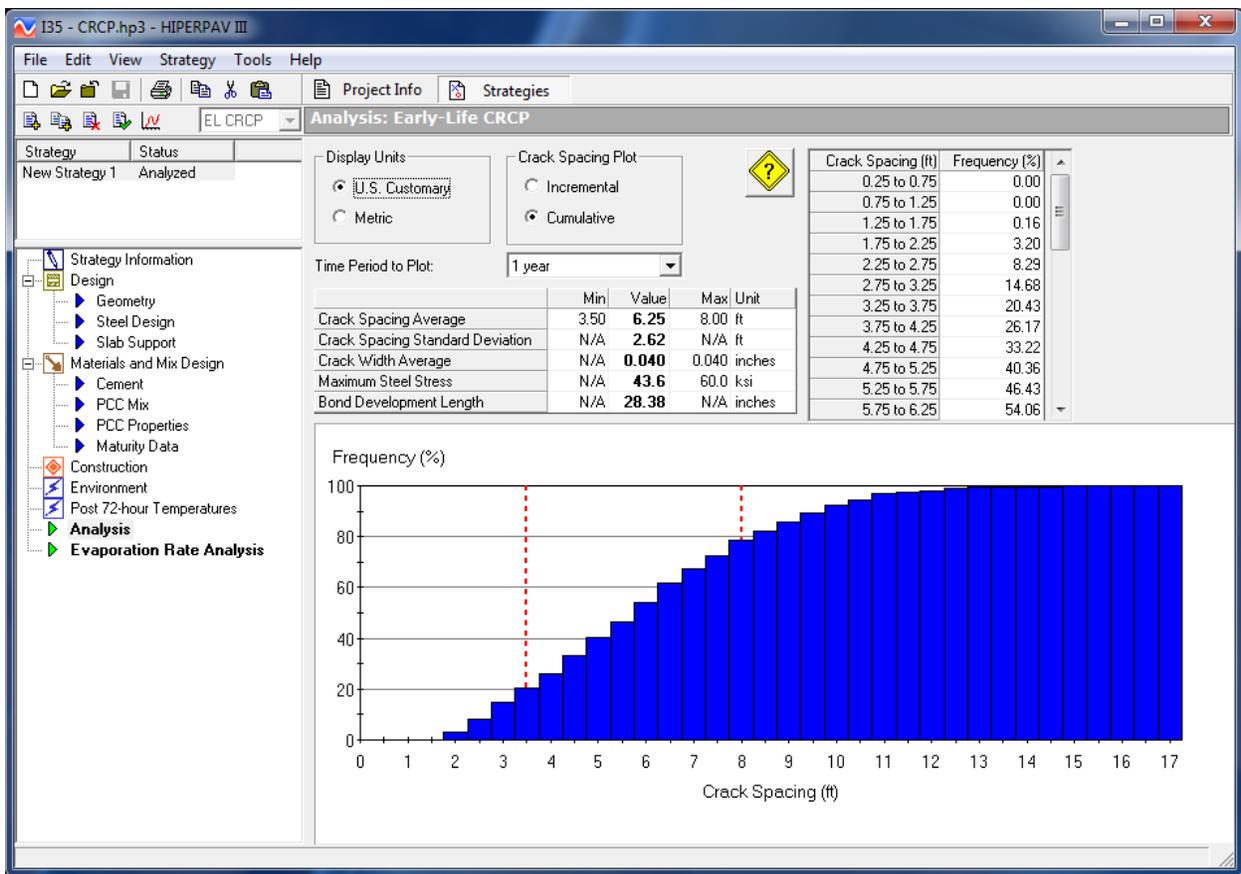


Figure 65. Screen Capture. Analysis window for early-age CRCP.

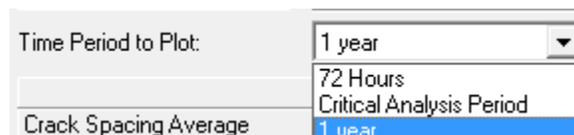


Figure 66. Screen Capture. Drop-down menu for time period to plot.

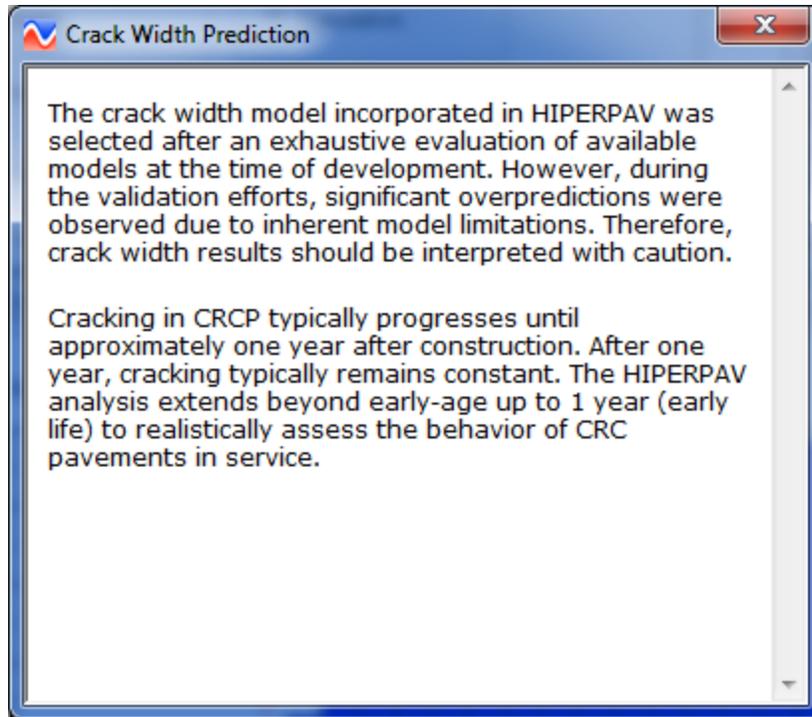


Figure 67. Screen Capture. Help icon under CRCP Analysis window.

Interpretation of CRCP Analysis

One of the objectives of the CRCP analysis is to achieve a crack spacing distribution that falls within the predefined thresholds, with only a small percentage of cracks falling above and/or below the maximum and minimum crack spacing limits, respectively, as shown in figure 65. In this analysis, both crack width and crack spacing are within acceptable limits. An example of a CRCP analysis with poor cracking characteristics is shown in figure 68. In this second analysis, neither crack spacing nor crack width fall within acceptable limits. In addition, a large percentage of crack spacings fall below the predefined minimum crack spacing threshold.

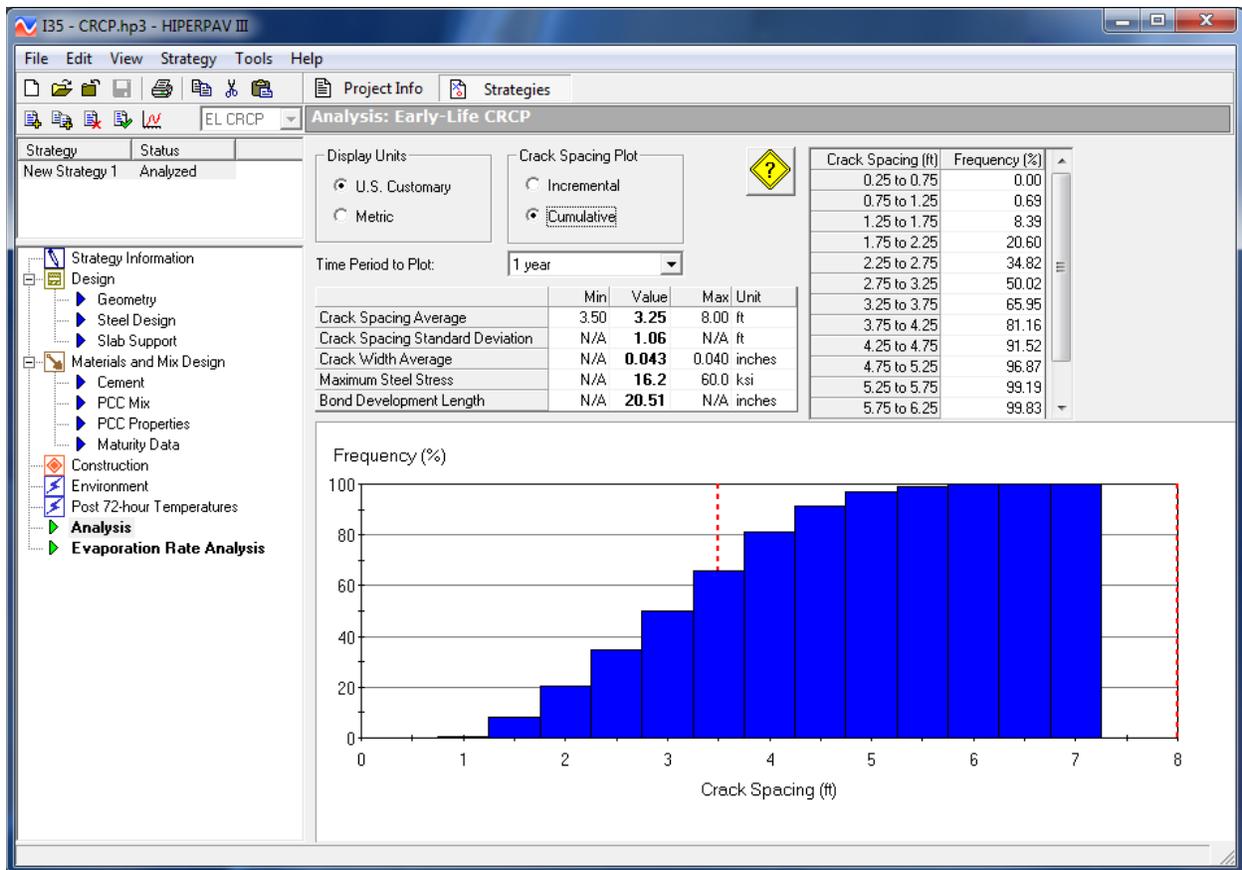


Figure 68. Screen Capture. CRCP analysis with poor cracking characteristics.

It is also recommended to compare the maximum steel stress predicted with the steel yield strength to evaluate the potential of wide cracks or steel rupture. The bond development length is predicted to compare with the predicted crack spacing. The user should achieve a minimum average crack spacing of twice the bond development length to ensure good CRCP behavior.

CHAPTER 5. REPORTS

For any HIPERPAV III® version 3.3 analysis, reports can be generated by clicking the print icon in the upper icon toolbar or by selecting “Print” from the file menu. After selecting “Print” a HIPERPAV® Report window is displayed as shown in figure 69. In this window, icons in the top left allow the user to print the report as shown, preview the report, and export the results to a Microsoft® Excel spreadsheet.

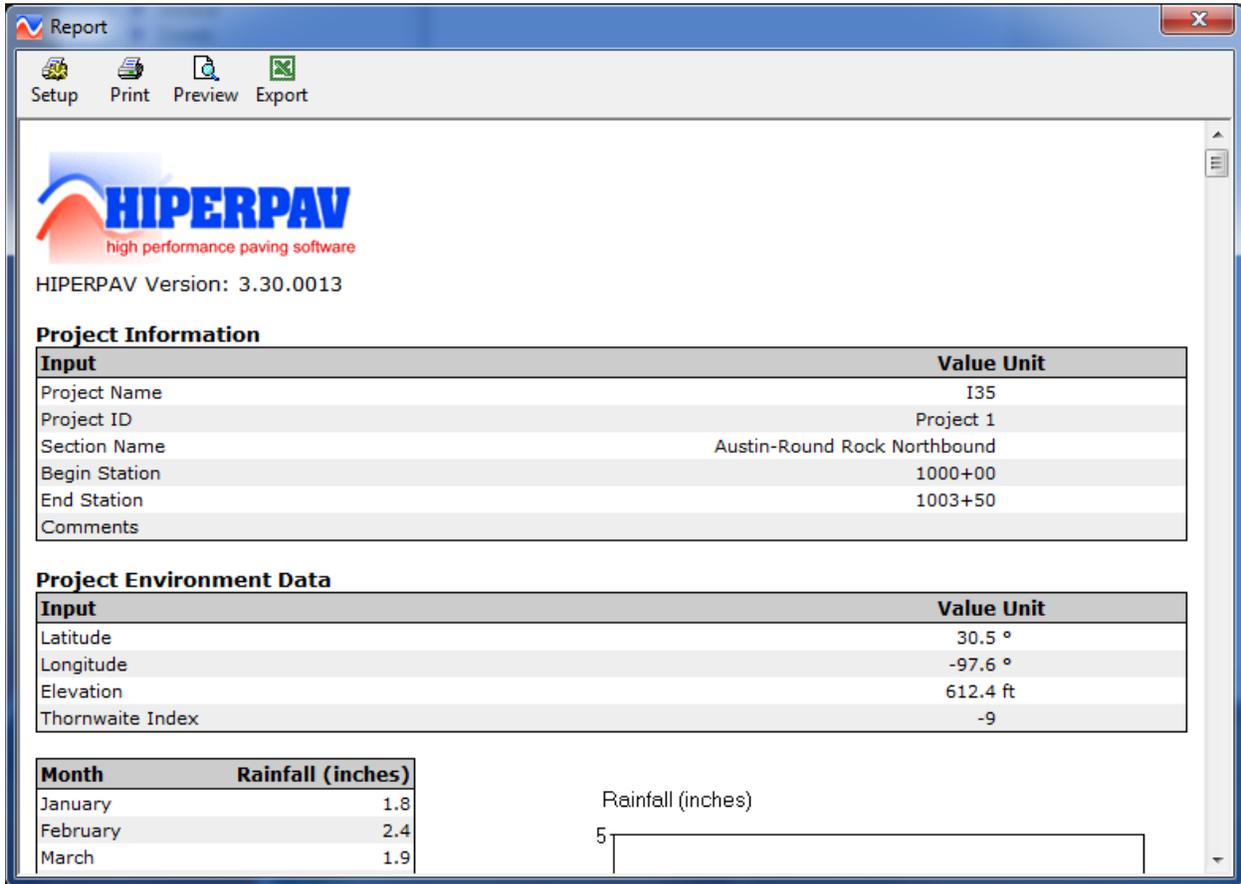


Figure 69. Screen Capture. HIPERPAV® Report window.

COMET MODULE

The Concrete Optimization, Management, Engineering, and Testing (COMET) module is a simplified derivation of the Concrete Optimization Software Tool that was developed by FHWA and the National Institute of Standards and Technology for optimizing concrete mixes. COMET can be accessed within HIPERPAV® by selecting “COMET” in the tools drop-down menu in the main toolbar, shown in figure 70. COMET optimizes concrete mixes based on early-age strength, 28-day strength, and cost.

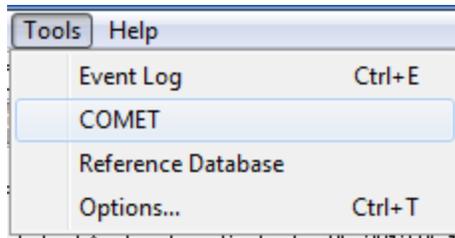


Figure 70. Screen Capture. Tools drop-down menu in HIPERPAV®.

Once selected, the initial COMET window appears as shown in figure 71. Inputs and outputs can be selected from the menu-like list on the left side of the window. The inputs for the window selected are displayed on the right. The first item on the tree view, “Event Log”, reports potential problems that may arise while running the software. Also, the tree view shows two levels of inputs and outputs. Level 1 inputs generate the experiment design of trial batches required for optimization. Level 2 inputs produce a set of optimum mixes based on the trial batch test results, and desirability functions defined for each response (early-age strength, 28-day strength, and cost).

As shown in figure 71, mix constituents are limited to cement, pozzolan, water, coarse aggregate, and fine aggregate. For each constituent, the specific gravity and cost is required.

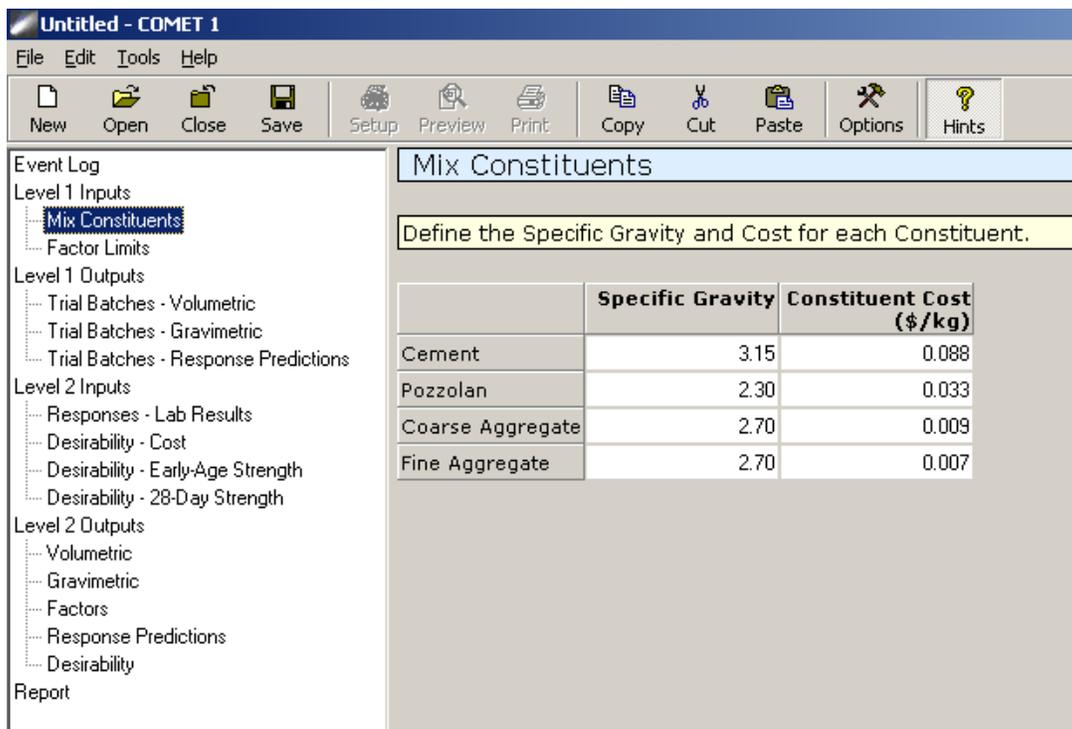


Figure 71. Screen Capture. Mix Constituents input window in COMET.

The user provides optimization ranges for coarse aggregate fraction, cementitious content, pozzolan substitution, and water-to-cement (w/cm) ratio (see figure 72).

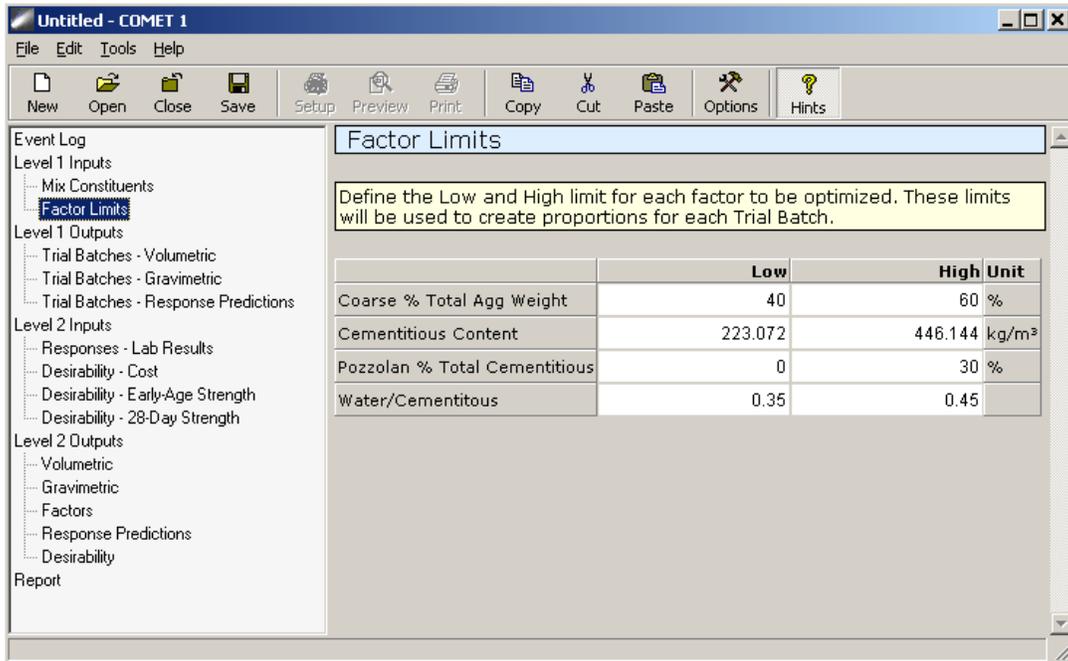


Figure 72. Screen Capture. Factor Limits input window in COMET.

With the inputs in Level 1, trial batches are developed for the experimental program by running the “Create Trial Batches” command button in the Level 1 outputs window, as shown in figure 73. As a result, 29 trial batches are generated, which can be displayed in volumetric (percent of total volume) and gravimetric (weight per unit of volume) form. The gravimetric form is presented in figure 74.

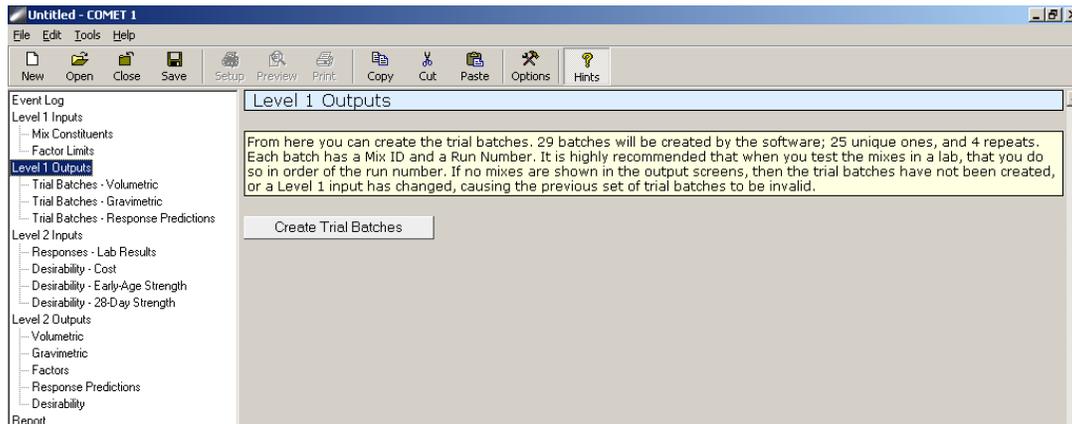


Figure 73. Screen Capture. Create trial batches command button in Level 1 Outputs.

Trial Batches - Gravimetric

Gravimetric data for each Trial Batch.

Run Number	Mix ID	Cement (kg/m ³)	Pozzolan (kg/m ³)	Water (kg/m ³)	Coarse Aggregate (kg/m ³)	Fine Aggregate (kg/m ³)	Total (kg/m ³)
1	1	223.1	0.	78.08	1436.	862.0	2599
2	2	156.2	66.92	78.08	1423.	853.7	2578
3	3	446.1	0.	156.2	1185.	710.7	2498
4	4	312.3	133.8	156.2	1159.	695.3	2457
5	5	223.1	0.	78.08	1642.	656.8	2600
6	6	156.2	66.92	78.08	1626.	650.2	2577
7	7	446.1	0.	156.2	1354.	541.7	2498
8	8	312.3	133.8	156.2	1324.	529.6	2456
9	9	223.1	0.	100.4	1398.	838.9	2560
10	10	156.2	66.92	100.4	1385.	831.2	2540
11	11	446.1	0.	200.8	1109.	665.7	2422
12	12	312.3	133.8	200.8	1083.	649.6	2380
13	13	223.1	0.	100.4	1598.	639.6	2561
14	14	156.2	66.92	100.4	1583.	633.0	2540
15	15	446.1	0.	200.8	1268.	507.3	2422
16	16	312.3	133.8	200.8	1238.	495.2	2380
17	17	284.4	50.19	117.1	1388.	693.5	2533
18	18	284.4	50.19	150.6	1327.	663.9	2476
19	19	284.4	50.19	133.8	1273.	763.5	2505
20	20	284.4	50.19	133.8	1454.	581.7	2504
21	21	189.6	33.46	89.23	1505.	752.3	2570
22	22	379.2	66.92	178.5	1210.	605.1	2440
23	23	334.6	0.	133.8	1368.	684.0	2520
24	24	234.2	100.4	133.8	1347.	673.4	2489
25	25	284.4	50.19	133.8	1357.	678.7	2504
26	26	284.4	50.19	133.8	1357.	678.7	2504
27	27	284.4	50.19	133.8	1357.	678.7	2504
28	28	284.4	50.19	133.8	1357.	678.7	2504
29	29	284.4	50.19	133.8	1357.	678.7	2504

Figure 74. Screen Capture. Trial batches in kg/m³, gravimetric form.

In addition, as shown in figure 75, the cost for every trial batch is computed, and default models in COMET are used to predict early-age strength and 28-day strength as a function of mix constituents. Predicted responses are only approximate and may be used in a planning stage in which the mix constituents may not be known or are not available for testing.

Trial Batches - Response Predictions

Predicted responses for each Trial Batch.

Run Number	Mix Number	Cost (\$/m ³)	Early-Age Strength (MPa)	28-Day Strength (MPa)
1	1	38.035	24.47	68.31
2	2	34.177	15.55	43.39
3	3	54.489	15.61	43.57
4	4	46.785	9.915	27.68
5	5	38.493	22.84	63.76
6	6	34.621	14.51	40.50
7	7	54.869	14.57	40.67
8	8	47.139	9.253	25.83
9	9	37.551	17.84	49.78
10	10	33.693	11.33	31.62
11	11	53.534	11.38	31.76
12	12	45.818	7.226	20.17
13	13	37.996	16.64	46.47
14	14	34.138	10.58	29.52
15	15	53.888	10.62	29.64
16	16	46.158	6.745	18.83
17	17	43.568	16.01	44.69
18	18	42.835	11.67	32.57
19	19	43.005	14.10	39.35
20	20	43.411	13.16	36.73
21	21	36.073	17.11	47.77
22	22	50.317	10.91	30.47
23	23	46.092	16.18	45.15
24	24	40.298	10.27	28.68
25	25	43.202	13.67	38.15
26	26	43.202	13.67	38.15
27	27	43.202	13.67	38.15
28	28	43.202	13.67	38.15
29	29	43.202	13.67	38.15

Figure 75. Screen Capture. Predicted responses for each trial batch.

After the Level 1 inputs and outputs are complete, the user can proceed with Level 2 analysis. To continue with this analysis, the user must enter the laboratory testing results for each response for the trial batches generated in Level 1 (see figure 76). Alternatively, the user may fill in these values using default models by clicking the “Reset to Predicted Values” command button, if a preliminary analysis is desirable.

Responses - Lab Results

You can use the predicted responses from the previous section or override them with your values from lab tests (recommended). Click the 'Reset' button to reset these values back to the predicted response values.

Reset to Predicted Values

Run Number	Mix Number	Cost (\$/m ³)	Early-Age Strength (MPa)	28-Day Strength (MPa)
1	1	38.035	24.470	68.310
2	2	34.177	15.550	43.390
3	3	54.489	15.610	43.570
4	4	46.785	9.915	27.680
5	5	38.493	22.840	63.760
6	6	34.621	14.510	40.500
7	7	54.869	14.570	40.670
8	8	47.139	9.253	25.830
9	9	37.551	17.840	49.780
10	10	33.693	11.330	31.620
11	11	53.534	11.380	31.760
12	12	45.818	7.226	20.170
13	13	37.996	16.640	46.470
14	14	34.138	10.580	29.520
15	15	53.888	10.620	29.640
16	16	46.158	6.745	18.830
17	17	43.568	16.010	44.690
18	18	42.835	11.670	32.570
19	19	43.005	14.100	39.350
20	20	43.411	13.160	36.730
21	21	36.073	17.110	47.770
22	22	50.317	10.910	30.470
23	23	46.092	16.180	45.150

Figure 76. Screen Capture. Lab results window.

The user can assign desirability functions for each of the optimization responses under the cost, early-age strength, and 28-day strength desirability windows. (A sample desirability function is shown in figure 77 for 28-day strength.)

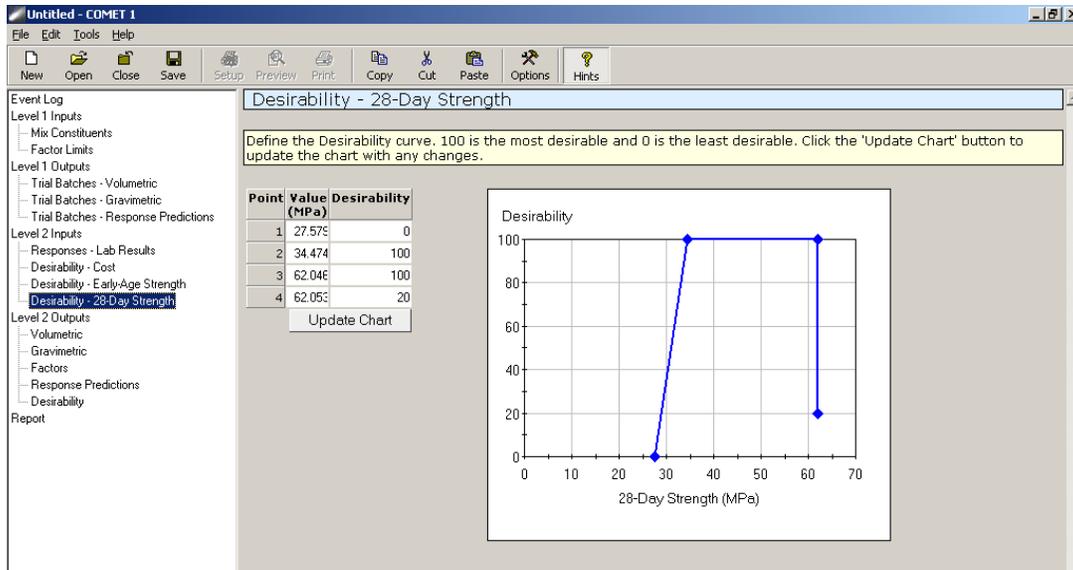


Figure 77. Screen Capture. Desirability function for 28-day strength.

After the Level 2 inputs are entered, optimization of mixes is performed by clicking the “Optimize Mixes” command button in the Level 2 outputs window (see figure 78). With this command, regression models based on the results from the experimental program or from the predicted responses are developed as a function of the mix proportions.

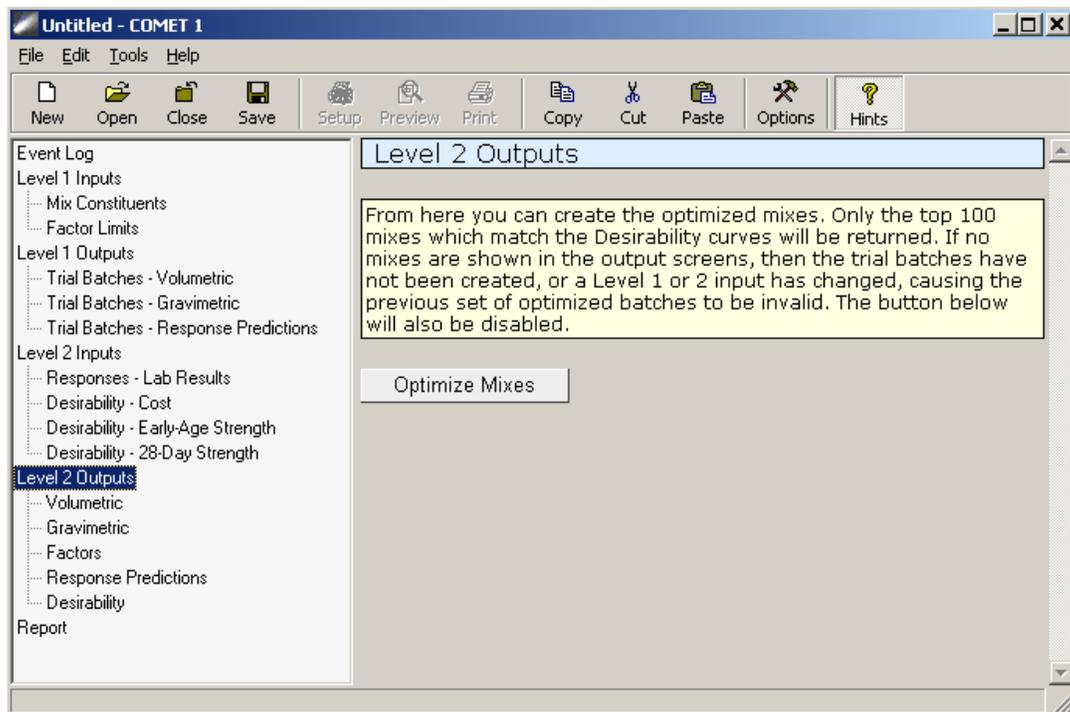


Figure 78. Screen Capture. Level 2 outputs—command to optimize mixes.

These models predict responses for a comprehensive set of mixtures within the factor limits specified in the factor limits window. Finally, optimum mixes are identified in terms of the

individual desirability for every response and the maximum overall desirability for all responses, and are presented in volumetric and gravimetric form. Optimum mixes are shown in volumetric form in figure 79.

Volumetric

Volumetric data for the optimized mixes.

Mix ID	Desirability	Cement	Pozzolan	Water	Coarse Aggregate	Fine Aggregate
1	86	0.04957	0.02910	0.09401	0.5171	0.3102
2	85	0.04957	0.02910	0.09401	0.5265	0.3008
3	85	0.04957	0.02910	0.09082	0.5191	0.3114
4	85	0.04957	0.02910	0.09082	0.5285	0.3020
5	85	0.04957	0.02910	0.08764	0.5211	0.3126
6	85	0.04957	0.02910	0.09082	0.5383	0.2922
7	85	0.04957	0.02910	0.08764	0.5305	0.3032
8	85	0.04957	0.02910	0.08445	0.5231	0.3138
9	85	0.04957	0.02910	0.09082	0.5484	0.2821
10	85	0.04957	0.02910	0.08764	0.5404	0.2933
11	85	0.04957	0.02910	0.08445	0.5326	0.3043
12	85	0.04957	0.02910	0.08126	0.5250	0.3150
13	85	0.04957	0.02910	0.09082	0.5590	0.2715
14	85	0.04957	0.02910	0.08764	0.5506	0.2831
15	85	0.04957	0.02910	0.08445	0.5424	0.2945
16	85	0.04957	0.02910	0.08126	0.5346	0.3055
17	85	0.04957	0.02910	0.07808	0.5270	0.3162
18	85	0.04957	0.02910	0.09082	0.5700	0.2606
19	85	0.04957	0.02910	0.08764	0.5611	0.2726
20	85	0.04957	0.02910	0.08445	0.5527	0.2842
21	85	0.04957	0.02910	0.08126	0.5445	0.2956
22	85	0.04957	0.02910	0.07808	0.5366	0.3066
23	85	0.04957	0.02910	0.09082	0.5814	0.2492
24	85	0.04957	0.02910	0.08764	0.5721	0.2616
25	85	0.04957	0.02910	0.08445	0.5633	0.2736
26	85	0.04957	0.02910	0.08126	0.5548	0.2853
27	85	0.04957	0.02910	0.07808	0.5466	0.2967
28	85	0.05261	0.02494	0.09720	0.5158	0.3095
29	85	0.04957	0.02910	0.08764	0.5836	0.2501
30	85	0.04957	0.02910	0.08445	0.5743	0.2626
31	85	0.04957	0.02910	0.08126	0.5654	0.2746
32	85	0.04957	0.02910	0.07808	0.5569	0.2864
33	85	0.05261	0.02494	0.09720	0.5252	0.3001
34	85	0.05261	0.02494	0.09401	0.5178	0.3107
35	85	0.04957	0.02910	0.08764	0.5955	0.2382
36	85	0.04957	0.02910	0.08445	0.5858	0.2511
37	85	0.04957	0.02910	0.08126	0.5772	0.2636

Figure 79. Screen Capture. Optimum mixes sorted by desirability in volumetric form.

In addition, the optimum mixes are also displayed in terms of the optimization factors, predicted responses, and individual response desirabilities as shown in figure 80, figure 81, and figure 82 respectively.

Untitled - COMET 1

File Edit Tools Help

New Open Close Save Setup Preview Print Copy Cut Paste Options Hints

Event Log

- Level 1 Inputs
 - Mix Constituents
 - Factor Limits
- Level 1 Outputs
 - Trial Batches - Volumetric
 - Trial Batches - Gravimetric
 - Trial Batches - Response Predictions
- Level 2 Inputs
 - Responses - Lab Results
 - Desirability - Cost
 - Desirability - Early-Age Strength
 - Desirability - 28-Day Strength
- Level 2 Outputs
 - Volumetric
 - Gravimetric
 - Factors
 - Response Predictions
 - Desirability
- Report

Factors

Calculated mix proportions for each optimized mix.

Mix ID	Desirability	Coarse % Total Agg Weight (%)	Cementitious Content (kg/m ³)	Pozzolan % Total Cementitious (%)	Water/Cementitious
1	86	40	223	30	0.421
2	85	43	223	30	0.421
3	85	40	223	30	0.407
4	85	43	223	30	0.407
5	85	40	223	30	0.393
6	85	46	223	30	0.407
7	85	43	223	30	0.393
8	85	40	223	30	0.379
9	85	49	223	30	0.407
10	85	46	223	30	0.393
11	85	43	223	30	0.379
12	85	40	223	30	0.364
13	85	51	223	30	0.407
14	85	49	223	30	0.393
15	85	46	223	30	0.379
16	85	43	223	30	0.364
17	85	40	223	30	0.350
18	85	54	223	30	0.407
19	85	51	223	30	0.393
20	85	49	223	30	0.379
21	85	46	223	30	0.364
22	85	43	223	30	0.350
23	85	57	223	30	0.407
24	85	54	223	30	0.393
25	85	51	223	30	0.379
26	85	49	223	30	0.364
27	85	46	223	30	0.350
28	85	40	223	26	0.436
29	85	57	223	30	0.393
30	85	54	223	30	0.379
31	85	51	223	30	0.364
32	85	49	223	30	0.350
33	85	43	223	26	0.436
34	85	40	223	26	0.421
35	85	60	223	30	0.393

Figure 80. Screen Capture. Optimum mixtures in terms of optimization factors.

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Event Log

- Level 1 Inputs
 - Mix Constituents
 - Factor Limits
- Level 1 Outputs
 - Trial Batches - Volumetric
 - Trial Batches - Gravimetric
 - Trial Batches - Response Predictions
- Level 2 Inputs
 - Responses - Lab Results
 - Desirability - Cost
 - Desirability - Early-Age Strength
 - Desirability - 28-Day Strength
- Level 2 Outputs
 - Volumetric
 - Gravimetric
 - Factors
 - Response Predictions
 - Desirability
- Report

Response Predictions

Predicted responses for each optimized mix.

Mix ID	Desirability	Cost (\$/m ³)	Early-Age Strength (MPa)	28-Day Strength (MPa)
1	86	33.824	12.50	34.88
2	85	33.889	12.40	34.61
3	85	33.902	13.19	36.81
4	85	33.954	13.09	36.54
5	85	33.967	13.90	38.79
6	85	34.020	12.98	36.23
7	85	34.020	13.80	38.51
8	85	34.033	14.62	40.82
9	85	34.072	12.85	35.87
10	85	34.085	13.68	38.18
11	85	34.098	14.51	40.52
12	85	34.111	15.36	42.89
13	85	34.138	12.71	35.48
14	85	34.151	13.55	37.82
15	85	34.151	14.40	40.19
16	85	34.164	15.26	42.58
17	85	34.177	16.12	45.00
18	85	34.203	12.56	35.05
19	85	34.216	13.40	37.42
20	85	34.216	14.27	39.82
21	85	34.229	15.13	42.24
22	85	34.229	16.01	44.68
23	85	34.268	12.38	34.56
24	85	34.281	13.24	36.97
25	85	34.281	14.11	39.40
26	85	34.281	15.00	41.86
27	85	34.294	15.89	44.33
28	85	34.308	12.93	36.09
29	85	34.347	13.07	36.47
30	85	34.347	13.95	38.94
31	85	34.347	14.84	41.44
32	85	34.360	15.74	43.95
33	85	34.373	12.83	35.83
34	85	34.386	13.62	38.01
35	85	34.412	12.87	35.91
36	85	34.412	13.77	38.43

Figure 81. Screen Capture. Response predictions for optimum mixtures.

Desirability

Predicted response desirability values for each optimized mix.

Mix ID	Desirability	Cost	Early-Age Strength	28-Day Strength
1	86	57	100	100
2	85	56	100	100
3	85	56	100	100
4	85	56	100	100
5	85	56	100	100
6	85	56	100	100
7	85	56	100	100
8	85	56	100	100
9	85	56	100	100
10	85	56	100	100
11	85	56	100	100
12	85	56	100	100
13	85	56	100	100
14	85	56	100	100
15	85	56	100	100
16	85	56	100	100
17	85	55	100	100
18	85	55	100	100
19	85	55	100	100
20	85	55	100	100
21	85	55	100	100
22	85	55	100	100
23	85	55	100	100
24	85	55	100	100
25	85	55	100	100
26	85	55	100	100
27	85	55	100	100
28	85	55	100	100
29	85	55	100	100
30	85	55	100	100
31	85	55	100	100
32	85	55	100	100
33	85	55	100	100
34	85	55	100	100
35	85	55	100	100
36	85	55	100	100

Figure 82. Screen Capture. Individual response desirabilities for optimum mixtures.

A report that can be used for printing the inputs and outputs for the entire analysis is generated, as shown in figure 83. To print, click on the print icon on the upper icon toolbar.

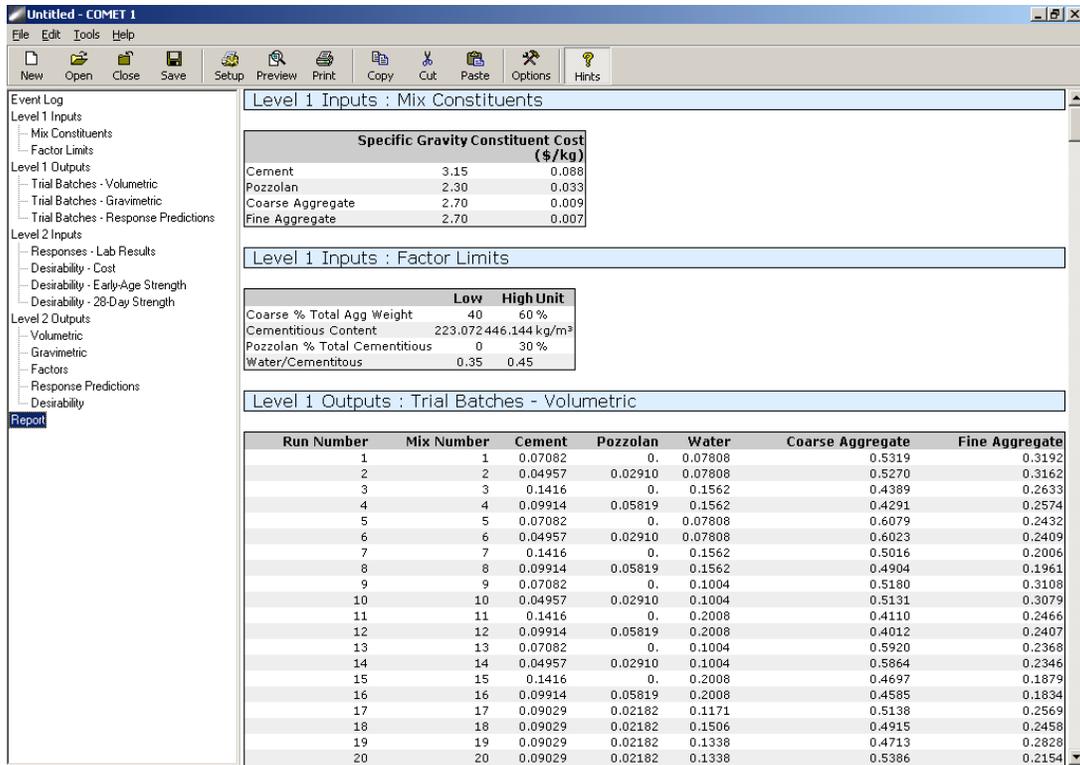


Figure 83. Screen Capture. Report view for printing purposes.

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