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Guide for Mechanistic-Empirical Design

OF NEW AND REHABILITATED PAVEMENT STRUCTURES

FINAL REPORT

APPENDIX D

NCHRP

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
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Submitted by
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Research Team Perspective, Future Research and Development Needs, and Acknowledgements

Perspective

The need for and benefits of a mechanistically based pavement design procedure were clearly recognized at the time when the 1986 AASHTO *Guide for Design of Pavement Structures* was adopted. The benefits are described in Part IV of that edition of the Guide. From the early 1960's through to the 1986 Guide, all versions of the Guide were based on limited empirical performance equations developed at the AASHO Road Test conducted near Ottawa, Illinois, in the late 1950's. Since the time of the AASHO Road Test, there have been many significant changes in trucks and truck volumes, materials, construction, rehabilitation, and design needs.

By 1986 it had become apparent that there was a great need for a design procedure that could account for changes in loadings, materials, and design features as well as direct consideration of climatic effects on performance. The AASHTO Joint Task Force on Pavements, in cooperation with the NCHRP and FHWA, sponsored the "Workshop on Pavement Design" in March 1996 at Irvine, California. The workshop participants include many of the top pavement engineers in the United States. They were charged with identifying the means for developing an AASHTO mechanistic-empirical pavement design procedure by the year 2002. Based on the conclusions developed at the March 1996 meeting, NCHRP Project 1-37A, Development of the 2002 Guide for Design of New and Rehabilitated Pavement Structures: Phase II, was awarded to the ERES Consultants Division of Applied Research Associates, Inc. in February 1998. The project called for the development of a guide that utilized existing mechanistic-based models and databases reflecting current state-of-the-art pavement design procedures. The guide was to address all new and rehabilitation design issues and provide an equitable design basis for all pavement types.

Design Challenges

NCHRP Project 1-37A called for the development of a design procedure based primarily on existing technology. The many requirements and expectations of the procedure made this requirement very challenging. This was the first pavement design procedure that incorporated both the impact of climate and aging on materials properties in an iterative (biweekly, monthly) and comprehensive manner throughout the entire design life. Most of the existing models had only limited usage with equivalent or worst-case materials properties being used as inputs. When varying materials properties and climatic conditions were applied using an incremental damage approach over the design period, some of the models gave erroneous results. As a result, significant resources were required to modify and adapt these models to work within the incremental damage approach. In addition, the hourly, monthly, and annual variations in traffic loadings were superimposed on changes to materials and climate to more realistically reflect the way in which pavements exist in-service.

Perhaps the greatest challenge was to calibrate the mechanistic-based conceptual models with nationally observed field performance data. This also had never been successfully accomplished before nationally. After the theoretical distress models (e.g., fatigue cracking, rutting, thermal cracking, joint faulting, slab cracking, punchouts) were formulated they were compared and calibrated against observed data. The results were then evaluated which lead to improvements to the model, which in turn required another time-consuming calibration. This process was repeated many times to achieve each of the final acceptable mechanistic-based distress prediction models. In the end, this laborious approach proved to be extremely valuable in producing models that could reasonably predict observed pavement performance. After model calibration was completed, design reliability was incorporated into the design procedure by considering the residual between observed and predicted distress. This approach was necessitated because computer run times for the simulation approach were not practical at this time but will be in the future.

The final challenge was to incorporate the complex models and design concepts into a stable and user-friendly software package. The NCHRP 1-37A team realized that no matter how technically correct the design method is, adoption of the software will be hindered if the software is not accessible and easy to use. Therefore, extensive effort was expended in making the software user-friendly and minimizes potential input errors. This was accomplished as follows:

- Inputs: Assurance that proper inputs are utilized through use of carefully selected default values, recommended and absolute ranges for each input.
- Help: Context-sensitive and on-line help.
- Outputs: Tabular and graphical Excel/HTML based outputs to help the designer visualize the performance of their trial design.
- Climatic database: Hourly climatic data from over 800 locations in North America are included, which allows the user to easily select a given station or to generate virtual weather stations.

Another very important aspect of the design procedure and software is that improvements can be made over time in a piecewise manner to any of the component models (distresses, IRI, climatic, traffic, materials, and structural responses) and incorporated into the procedure for re-calibration. The framework has been laid for future updates. Ranges and default values of design inputs can be set by local agencies. The key limitation is the longer run time for flexible pavement design and rehabilitation. This can be improved through software optimization.

Future Needs for Continued Improvement of the Design Guide

Perhaps the most important characteristic of the Design Guide is its technological and modular framework for pavement design and its calibration-validation process. The bi-monthly/monthly incremental damage approach makes it possible to improve virtually any model and algorithmic subsystem over time. Any model or algorithm, from the various structural responses models to modulus prediction models to fatigue damage models, can be replaced with improved versions as they become available with further research. However, changes to models or algorithms that affect distress and smoothness predictions may require re-calibration with field data. The Design Guide provides the needed “focal” point for development and improvement of pavement design over time.

The NCHRP 1-37A project was required to use proven state-of-the-art technology. While this gave the research team a lot of possibilities, it restricted the team and prevented the use of some technology that might, after additional development, have resulted in better prediction models. However, it soon became apparent that even supposedly proven technology had major problems and required significant improvements and modifications before it would work within the mechanistic design framework. Many needed improvements were accomplished, but within the complex engineering system developed there exists several areas that need further development. The research team and the many individuals who assisted in reviewing the design procedure over the past several years identified a number of aspects that could be improved. This section provides a brief summary of those improvements.

Climatic Modeling

One of the major advances of the Design Guide was to integrate the weather station driven EICM model (Enhanced Integrated Climatic Model) directly with procedures to predict pavement and subgrade layer material modulus changes and gradients due to changes in temperature and moisture content within the pavement structure. The layer moduli values and temperature and moisture gradients and their integration within a comprehensive structural analysis methodology were implemented into the Design Guide to provide capabilities never before available. However, there are still several issues that need to be addressed in order to improve the accuracy of the overall climatic-materials interactive subsystem. Major changes in the subsurface moisture distribution had to be made in the EICM version to improve the predictions of the subsurface moisture content. These changes, predominantly in the SWCC relationships used to define the state of soil suction, were implemented and are now a part of the latest EICM version used in the Design Guide.

NCHRP 9-23 is nearing completion to enhance the subsurface moisture prediction methodology in the EICM and it is recommended that the NCHRP 9-23 results, conclusions, and suggested modifications to the EICM moisture model be directly incorporated into the Design Guide. There are several other minor areas that need further improvement in the EICM model. Problems still exist with the prediction of moisture in quality granular bases. The problem that occurs is that, due to the soil suction properties of these materials, little, if any, moisture can be drawn into the layer due to suction. For flexible pavement, no surface infiltration was allowed. As a consequence, moisture contents become exceedingly low, and base moduli are predicted to be abnormally high. A better infiltration model for both rigid and flexible pavements that predicts infiltration over time is needed. Finally, the current version of the EICM model in the Design Guide still uses an “empirical” recovery period, based upon soil type, to define the moisture – time changes after thaw weakening has occurred. It is recommended that a more mechanistic solution for this recovery process be developed.

Another aspect which will require continual, periodic updates to the Design Guide software involves updating the weather station databases with the latest information from the NCDC. The design guide at the present time contains historical hourly weather information for approximately 800 weather stations in North America. At the time the performance models were calibrated, for most of these stations, the historical records contain information that spans over a five-year period. However, it is recognized that an enhanced database will perhaps lead to a better calibrated models and will also help establish the key climatic variable more accurately.

Design Reliability

The procedure for design reliability included in the Design Guide while considered adequate for initial implementation should be considered as a place holder for a more comprehensive procedure. The identification of an improved methodology for design reliability is considered a top priority by the research team. The current method for incorporating reliability into the Design Guide is based upon the assessment of the overall standard error of the predicted distress as compared to observed distress. An improved procedure should make it possible to consider all of the key components of variability and uncertainty involved in pavement design. This would make it possible for the designer to input the mean, variance, and distribution of many key inputs and also incorporate the errors associated with the prediction models providing for a much more accurate design reliability. The designer would then be able to determine the sensitivity of the outputs (cracking, rutting, faulting, IRI, etc.) to variations in the inputs providing designers with improved knowledge of the most critical inputs that should be estimated with greater accuracy.

It is highly recommended that a continuing effort be made to incorporate such a design reliability approach in a reasonable and practical manner. It is cautioned, however, that a critical factor in this solution will be related to the computational time required for such an analysis which makes a Monte Carlo simulation approach somewhat impractical. There exist a number of modern approaches to reliability that can be explored that should provide a reasonable solution that makes it possible to have the above desired characteristics.

However, with such a more comprehensive reliability approach, the estimation of all associated variances and uncertainties will be required. This will require a large major research effort. This would include estimation of variations and uncertainties associated with traffic loadings, climate, material properties, layer thickness, and many other design inputs. It would also include errors associated with all models included in the design guide. An improved reliability procedure should not be attempted if a large allocation of resources is not available to estimate all of the applicable variations and uncertainties associated with all inputs and models. Such a procedure without good estimates of variances of all key inputs and prediction models would be completely misleading and erroneous.

Calibration-Validation of Prediction Models for Level 1, 2, and 3 Inputs

The major premise, upon which the hierarchical input system was devised, is that the standard error associated with the prediction of a given distress mode decreases as the level of engineering effort, intensity and testing is increased. This can be stated in an alternate manner by understanding that the reliability of the design prediction should logically increase when the level of the engineering effort used to obtain inputs is increased. This would logically lead to a reduction in life cycle costs of pavements.

In the Design Guide, it was only possible to demonstrate that this concept was applicable and valid for the thermal fracture module. It is recommended that this hypothesis be confirmed, to the practicing profession, for at least one major mode of load-associated distress. This is necessary because it is very important to illustrate to the engineering community that additional time, effort and design funding will actually result in a lower cost and longer performing product. If this is not demonstrated quickly, it is possible that engineers may simple be lulled into using a Level 3 (empirical correlations and default values) as the primary (and perhaps only) procedure to obtain inputs.

Conduct Additional Sensitivity Studies

A significant effort was expended in this study to complete a series of comprehensive sensitivity studies on a very wide range of design variables for several models. These included alligator (bottom up) and longitudinal (surface down) fatigue cracking and permanent deformation in flexible pavements. Bottom up and top down fatigue cracking for JPCP, joint faulting for JPCP and punchouts for CRCP were also included. While this was a monumental effort; there are still several major additional sensitivity studies that need to be completed for various other models related particularly to rehabilitation.

A major effort needs to be made to assess the sensitivity of reliability for the complex issue of rehabilitated flexible pavement and rigid pavement systems. Limited sensitivity runs were evaluated in the initial development of the Design Guide. However, a more extensive study needs to be completed for all major asphalt rehabilitation categories developed: HMA overlays of existing HMA pavements; HMA overlays of fractured PCC slabs and HMA overlays of sound (intact) PCC systems. For PCC rehabilitation categories it includes restoration, unbonded PCC overlays, bonded PCC overlays, and PCC overlays of flexible pavements.

Improve Accuracy of LTPP Database for Calibration-Validation of Distress/Smoothness Models

The LTPP database was a major asset for the calibration and validation studies performed in the development of the Design Guide. It also became apparent that there were many limitations associated with the LTPP database relative to its usefulness as a major tool in the performance calibration of the Design Guide. A large amount of project resources were expended to improve on the LTPP database for use in calibration. For instance, many time-series distress data varied considerably over time, requiring the research team to examine every field data sheet to clear up as many as possible. It is recommended that action be taken to improve the accuracy of entries in the LTPP database. As such improvements are made, the LTPP sections within each state could become more useful to local implementation and calibration efforts. LTPP should revaluate the importance of the national database as an essential tool that should feed directly into national and regional calibration studies of the Design Guide.

Two very important elements of the database that are missing are as follows. It is critically important that trench studies be completed on certain LTPP flexible test sections that would be designated as pavements to be used in any subsequent layer rutting calibration-validation project. Without trenching data; it is physically impossible to accurately calibrate any type of rutting model for flexible pavement systems. The second factor noted already relates to the field verification of the surface down (longitudinal) fatigue cracking mechanism for both flexible pavements and JPCP. It is very apparent that the existence of top down cracking can only be completely ascertained by conducting a field core-crack depth assessment study on selected LTPP sections.

Another important issue related to the LTPP distress identification procedure used is to modify the existing procedure to better identify longitudinal cracking. It is necessary to identify types of longitudinal (and even alligator cracking) that occur within the wheel paths. At present, there is no known way for researchers, using the database, to distinguish cracking that is solely related to load cracking (it would be assumed that all cracking in any wheel path is load associated) and cracking that is non load related, such as longitudinal cracking reflected from existing construction joints or lane widening. The manner in which distresses are recorded should be reexamined, with the intention that the ultimate goal of the distress database is to use the distress measurements in some form of structural (or even non-structural) models for calibration-validation purposes.

It is recommended that the seasonal levels of Ground Water Table (GWT) be measured. The same level of importance can also be stated for the depth to bedrock. The sensitivity runs of these two variables have pointed out that they may be significant variables influencing pavement distress and performance. Best estimates and county soil maps were used to estimate these parameters for the calibration.

National Center for the Coordination of State Calibration Efforts for Flexible and Rigid Pavement Systems

It is recommended that a concerted national effort be made to establish a center that would serve to develop and house a complete materials database on a variety of tests that are required (or will be required) for implementing the Design Guide. It is hoped that as State DOT / Universities conduct material evaluations for their own DOT; their results can be placed in the National Center database to add to those material responses that were originally used in the development of the Design Guide models. The center could also house traffic databases developed by various States that would help to fulfill or help validate the needs of each agency for traffic inputs. Information and contents of the database would be freely accessible to all agencies supporting the Center. There may be other dta that could also be houses by such a center such as climatic data.

Improve Accuracy of Smoothness (IRI) Models

The Guide includes several models for IRI prediction for various types of flexible pavements, rigid pavements, and various overlays. These empirical based models were developed based on a limited number of LTPP sections. These models have serious deficiencies that will become evident as they are used in pavement design and are in great need of improvement. These models should be considered placeholders for new and improved models that could be implemented in the future. There exists today substantially more data from which improved models could be developed. However, since smoothness is such a critically important user consideration, and is also the only performance indicator that is common between flexible and rigid pavements, it is recommended that a major effort be initiated to predict smoothness in a more mechanistic based manner. The smoothness models would input the M-E based distress prediction, the initial as-built smoothness, and other parameters (e.g., foundation movement) needed for the prediction over the design life. This would undoubtedly improve the accuracy and capability of smoothness in the Design Guide.

HMA Pavements and Overlays

An enhanced calibration-validation effort is greatly needed. Although the research team spent a lot of resources trying to obtain valid LTPP data, there was much missing data and only a small fraction could be used in calibration for new and overlaid pavements. The results of the effort shown in flexible pavement calibration-validation appendices for data (Appendix EE), fatigue cracking (II), permanent deformation (GG), and thermal cracking (HH) reflect a major effort of calibration and validation of the initial distress models for new asphalt pavement systems. However, it is quite obvious that some significant limitations were associated with the available performance data used from the LTPP sections that are in need of a considerable effort to improve their accuracy. A major recommended future need is to greatly increase the number of design sections used in the calibration of the fatigue and permanent deformation modes of distress.

A very important element of these additional test sections is that they should conform to two critical recommendations that were suggested by Witczak et al and the Superpave Support and Performance Models Management Team (FHWA Contract DTFH61-95-C-00100) in the 30 September 1996 "Models Evaluation Report". In this report to the FHWA, it was urged (and repeated in several other ensuing report documents) that "In addition to measurement and classification of surface distress, all pavement sections included in the experimental designs for load related distress, particularly permanent deformation, will require trench studies to apportion distress (rutting) distributions between the bound and unbound layers. These studies will be conducted in conjunction with material sampling required for the unbound materials test plan described in Section 6.2". None of the LTPP test sections used in this study effort for the main calibration effort had trench data. Only surface (total) rutting was available. As such, it is the belief of the research team that a very large portion of the "predictive rut depth error" is directly due to the fact that actual deformations within material layer types were not available for the initial calibration study.

Longitudinal surface (top-down) cracking prediction model was based on the assumption that all longitudinal cracking in the LTPP database (in the wheel paths) were load associated and propagates from the surface down. As pointed out by Witczak et al and the Superpave Support and Performance Models Management Team (FHWA Contract DTFH61-95-C-00100) in the 30 September 1996 "Models Evaluation Report"; it was noted that "Substantial field data from the United States, the Middle East, and Southeast Asia suggests that significant fatigue cracking can initiate and propagate from the surface of asphalt concrete pavement layers. This is in contrast to the traditional model, which considers the bottom of these layers as the only locus of fatigue cracking. The performance model for fatigue cracking must account for this failure mechanism if it is confirmed through careful field studies. Thus, the materials data collection plan requires the sampling of pavement cores directly through fatigue cracks in order to evaluate the location of crack initiation and the direction of its propagation in the asphalt layers." It will not be possible to pursue further calibration-validation studies for either permanent deformation (bound and unbound layers) or top down longitudinal surface cracking until LTPP sections can be trenched and a field core-crack study completed. Once this is completed, the additional sections would be quite helpful to verify (modify) several critical assumptions made in the initial effort as well as being combined with the original sections used to develop the initial national calibration factors developed in this study. It is noted that a study (NCHRP 1-42) is already underway on this topic.

In addition to more LTTP sections for enhancing the calibration of fatigue and rutting in new sections; it is recommended that additional efforts be made to expand the calibration-validation of the rehabilitated sections as well. Here, the selection of additional sections having HMA overlays over existing HMA pavements, PCC fractured slabs (crack-seat; break-seat and rubblized PCC); JPCP, and CRCP pavements as well as pavements having chemically stabilized layers needs to be analyzed with a much more comprehensive calibration effort that was possible within the time and funding restraints of the initial study.

Enhance/improve existing models to increase accuracy. It should be recognized that several key model selections and approaches were decided several years ago in the early stages of the project. Since this time, the "state of the art" has continuously advanced as well as other technologies that were available but required additional development may have produced more accurate distress models. While the current methodology is felt to provide a strong foundation for the prediction of distress in a mechanistic-empirical framework, there are several model advances that should be undertaken to assess if they can significantly increase the accuracy of the predicted distress.

The reflective crack model for HMA overlays is an empirical place holder for the future development and implementation of a M-E based reflective crack model. This is one of the most critical research needs for flexible pavements. The enhancement of the top-down surface fatigue model with a more fundamental approach is also considered as a top research need.

One of the major goals of the NCHRP 1-37A project was to integrate the major HMA mixture response results from the NCHRP 9-19 (Superpave study) which is nearing completion. In essence, the ultimate goal is to integrate HMA mixture design within a structural design framework. It is recommended that the enhancement of this process should be to integrate the NCHRP 9-19 work with Flow Time (Ft) and Flow Number (Fn) into the permanent deformation models for asphalt mixtures used in the current Design Guide. Both the Ft and Fn values are Tertiary flow mix parameters of an asphalt mixture. In the current Design Guide, only the secondary rutting phase is modeled by the $\varepsilon p/\varepsilon r$ power model used. Thus the inclusion of a methodology to also consider tertiary (plastic shear failure) in a structural model would be a very significant enhancement to the Design Guide.

The current Design Guide rut model for HMA rutting was found to need an empirical relationship to adjust the rutting as a function of the depth within the asphalt thickness. This equation turned out to be a 5^{th} order polynomial that accurately predicted the in-situ rutting-depth profile for several MnRoad sections. While this modification was statistically developed; it has the general appearance of the typical relationship of shear stress with depth within a Boussinesq solid. It would be quite important to assess if this depth relationship would actually conform to a more rational distribution associated with the maximum shear stress-depth relationship found from mechanics, rather than from pure empiricism.

Reduce the computational time for flexible pavement design. The flexible pavement team devoted a continuous effort in trying to reduce the computational time for the flexible pavements analyzed in the Design Guide. A very significant decrease in runtime has simply been a result of the generation of the microprocessor used in the analysis. In the early stages of the software development; average runtime on what was then conceived to be a "fast" microprocessor (500 MHz system) was about 5.1 minutes per analysis year. With present day 2.8 GHz units, the time has been reduced to under 1.4 minutes per analysis year. Without any major changes in software code, it is estimated that for future 4.0+ GHz units; the average runtime may actually approach about 1 minute per analysis year. When one considers the complexity of the asphalt portion of the Design Guide, along with the hundreds of thousands of incremental damage computations conducted within an analysis run; the time is not excessive. Nonetheless, it is apparent that significant trade-off in time reduction could be made if certain assumptions were "relaxed" more than they currently are. It is recommended that continuous efforts be undertaken to reduce the computational time for the program.

Enhancements to the Witczak et al E* predictive model are needed. The dynamic modulus predictive equation for asphalt mixtures, developed by Witczak and a vast array of colleagues, is an important component of the hierarchical structure of the Design Guide. While this equation is considered quite accurate and has been developed from the E* lab test results of nearly 150 HMA mixtures and 1500 data points; there is an opportunity to nearly double the number of mix types and increase the total number of data points to approximately 6000 by adding a significant number of E* results that have been collected at ASU from several new major studies that have been completed (NCHRP 9-19; ADOT 2002 DG Implementation; ADOT AR Projects). The objective of this study would be to combine all available E* results and perform a new round of statistical studies to develop a new, more accurate predictive model. The intention of this effort would be focused upon keeping the same "sigmoidal" functional form as the current model; but trying to develop a more accurate assessment of the volumetric components of the mix (air voids, asphalt volume etc.). This minor change would definitely lead to more rational distress predictions in the Design Guide, particularly for HMA rutting and fatigue fracture. A final effort should also be focused upon assessing whether or not the current "Ai-VTSi" viscosity characterization could be completely replaced by the new Performance Grade (PG) binder properties such as G* (Dynamic Shear Modulus). If the use of the G* (binder) is found to be feasible, the use of this binder property, rather than the use viscosity, would bring the entire HMA material characterization process into a much more current methodology.

Conduct initial calibration trials of FEM technology for asphalt pavement systems. All of the load associated calibration efforts used in the Design Guide has been based upon the linear elastic layered pavement response model (JULEA). However, a finite element pavement response model is also included for the case when a Level 1 input is desired for the use with non-linear resilient modulus (Mr) of any unbound base, subbase and/or subgrade layer. The limitation of this approach, however, is that it has not been calibrated. It is therefore recommended that an initial effort be undertaken to start a calibration with LTPP sections that have been used in the initial NCHRP 1-37A study. Because the complexities and problems that may surface with the FEM calibration process are unknown at this time; it is recommended that only a handful (6-8) LTPP sections be initially selected, Level 1 Mr testing be completed on all unbound layers, and a pilot calibration study completed. After this pilot study is completed, plans and scheduling of a major FEM calibration can be developed, using insights obtained from the pilot effort.

<u>Concrete Pavements & Overlays</u>
The current Design Guide can only handle PCC overlay thickness of 6 in and greater. A major effort is needed to develop procedures for thinner PCC overlays including the ultra thin overlays that are bonded to the asphalt surfacing. More adequate characterization of the existing HMA

pavement will also be required. This may require a more comprehensive structural modeling as well as improved knowledge on the bonding of PCC to HMA. This is considered a priority for improvement of the PCC rehabilitation design procedure.

Shrinkage of the top portion of the PCC slab is directly considered in design in two modes: permanent and transitory (varying with monthly relative humidity). The methodology, however, is not nearly as comprehensive or reliable as is needed to match the level of accuracy that exists for temperature gradients through PCC slabs. The method of incorporating permanent shrinkage into the permanent curl/warp needs to be improved. The existing Design Guide shows a continuing increase in shrinkage over many years resulting in the opening of cracks and joints over a long time period. While this does occur, the magnitude needs better estimation procedures.

Zero-stress temperature is the temperature at which after placement the PCC becomes solid enough to go into tension. This temperature is used as the basis to compute the openings of cracks and joints which affect the transfer of shear and load and crack load transfer over time. Improved procedures are needed to estimate this important parameter in design of JPCP and CRCP.

Permanent curl/warp effective temperature difference is a critical input that needs further calibration and amplification. This input is used to predict top down and bottom up slab cracking and also joint faulting. This value was obtained nationally through optimization of cracking of JPCP for many LTPP and other sections across the U.S. There area no procedures to adjust this input to consider other construction situations (e.g., night time construction, wet curing, hot desert paving, and so on). Obtaining better estimates of this input for varying construction conditions would greatly improve the ability to take construction and materials into consideration in the design phase.

The coefficient of thermal expansion/contraction (CTE) is a new and most significant input to the new rigid design procedure. Since this input has not before been measured and used in design much more information is needed to help the designer estimate this input adequately. The extensive LTPP data could be analyzed to further develop improved recommendations for CTE as well as extensive additional lab studies carried out for a variety of aggregates and other components of today's PCC mixtures.

The CRCP procedure includes methodology to predict both crack spacing and crack width. While these models are very comprehensive and mechanistic based, additional validation is greatly needed since they play a very critical role in the performance of CRCP. The crack deterioration model which controls punchout development depends greatly on crack width and thus development of punchouts is critical. Very little validation of the crack deterioration model was possible and more is needed. One variable that is missing is top aggregate size which has a major effect on crack load transfer efficiency.

An enhanced calibration-validation effort is greatly needed for rigid pavements. Although the research team spent a lot of resources trying to obtain valid LTPP data, there was much missing data and only a small fraction could be used in calibration for new and overlaid pavements. The results shown in various calibration-validation appendices include data (Appendix FF), CRCP punchouts (Appendix LL), joint faulting (Appendix JJ), transverse fatigue cracking (appendix KK), and rehabilitation (Appendix NN) reflect a major effort of calibration and validation of the load associated distress models for new and rehabilitated concrete pavements. However, it is quite obvious that some significant limitations were associated with the available performance data used from the LTPP sections that are in need of a considerable effort to improve their accuracy.

There is a great need for additional PCC rehabilitated sections including concrete pavement restoration, unbonded PCC overlays, bonded PCC overlays, and PCC overlays of flexible pavements. Particularly needed are JPCP and CRCP overlay sections which are being used routinely by several states. With these data, a much more comprehensive calibration-validation effort could be conducted with the result of improved distress prediction models for all these PCC rehabilitations. There is also a great need for low volume road sections for use in better calibration of these types of pavements.

Enhance/improve existing models to increase accuracy in prediction. It should be recognized that several key model selections and approaches were decided several years ago in the early stages of the project. Since this time, the “state of the art” has continuously advanced. In addition, there were other technologies that with further development could likely have produced improved distress prediction models. While the current methodology is felt to provide a strong foundation for the prediction of distress in a mechanistic-empirical framework, there are several model advances that should be undertaken in the future to assess if they can significantly increase the accuracy of the predicted distress.

One of the major goals was to integrate some PCC mixture and construction factors into the structural design process. It has been long recognized that PCC mixture design and construction aspects strongly relate to ultimate long term performance of all types of rigid pavements and thus this capability would provide a major enhancement to the structural design of a PCC pavement. A major initial effort was made to incorporate several key mixture and construction factors, however, addition development and improvement is greatly needed. PCC mixture parameters incorporated include the various measures of strength (and its gain over time), the elastic modulus (and its gain over time), the w/c ratio, cement content and type, thermal coefficient of expansion, and relative drying shrinkage through the slab over time. Construction factors include the zero-stress temperature of the slab after placement and the permanent curl/warp equivalent temperature difference. While these important factors are included in the design process, methods to estimate them for design are limited and several are considered only rudimentary. Thus, great improvement is possible and needed.

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Project Management

Mr. John P. Hallin of ERES Consultants Division of Applied Research Associates, Inc. (ERES) served as the Principal Investigator, and Mr. Ken McGhee with Fugro-BRE, Inc. served as the Co-Principal Investigator.

Flexible Pavement Team

Dr. Matthew W. Witczak of Arizona State University headed the flexible pavement team. Members of the flexible pavement team were:

- Arizona State University: Mohamed El-Basyouny, Waseem Mirza, Claudia Zapata, Dragos Andrei, and Manuel Ayres.
- Fugro-BRE, Inc.: Harold Von Quintus (also served on the ERES team).
- University of Maryland: Charles Schwartz.
- Advanced Asphalt Technologies, LLC: Ray Bonaquist.
- University of Illinois, Urbana-Champaign: William Buttlar.
- Consultant: Jacob Uzan.

The following provided support to the flexible pavement team:

- Chandra Desai, Kamil Kaloush, Bill Houston, Mohammad Abojaradeh, Javed Bari, Shudong Guan, Herve DiBenedetto, Manfred Partl, Tehri Pellinen, Darius Sybilski, Ken Walsh, Andres Sotil, and Sherif El-Badawy (Arizona State University).
- Amy Simpson, Ahmed Eltahan, Weng-on Tam, Amber Yau, (Fugro-BRE, Inc.).
- Yongyi Feng and Yiquan Hu (University of Maryland).

Rigid Pavement Team

Dr. Michael I. Darter of the ERES Consultants Division of Applied Research Associated, Inc. headed the rigid pavement team. Members of the rigid pavement team were: Lev Khazanovich, H. Thomas Yu, Leslie Titus-Glover, Jagannath Mallela, Chetana Rao (also prepared training and implementation materials), and Olga Selezneva.

The following provided support to the rigid pavement team:

- Kelly L. Smith, Shreenath Rao, and Jane Jiang (ERES).
- Dan G. Zollinger (Texas A&M University).
- Mark B. Snyder (formerly with the University of Minnesota).

Software Team

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TABLE OF CONTENTS

PART 1—INTRODUCTION

CHAPTER 1: BACKGROUND, SCOPE, AND OVERVIEW....................................1.1.1

1.1.1 BACKGROUND 1.1.1

1.1.1.1 Objective of the Design Guide..1.1.1

1.1.1.2 Economic Justification for a Revised and Improved Design Guide......1.1.1

1.1.1.3 Need for the Design Guide 1.1.3

1.1.1.4 Philosophy of the Design Guide Development.....................................1.1.5

1.1.1.5 Benefits of a Mechanistic-Empirical Procedure 1.1.5

1.1.2 PRINCIPLES OF A MECHANISTIC PROCEDURE..................................1.1.7

1.1.3 SCOPE AND CONTENTS OF THE GUIDE 1.1.9

1.1.4 DESIGN APPROACH..1.1.11

1.1.4.1 General Approach 1.1.11

1.1.4.2 Hierarchical Design Inputs 1.1.14

1.1.5 PAVEMENT PERFORMANCE 1.1.15

1.1.6 TRAFFIC CHARACTERIZATION...1.1.18

1.1.7 PAVEMENT MATERIAL CHARACTERIZATION................................1.1.18

1.1.7.1 General Considerations...1.1.18

1.1.7.2 Classes of Materials 1.1.19

1.1.7.3 Levels of Materials Characterization 1.1.20

1.1.8 STRUCTURAL MODELING OF THE PAVEMENT 1.1.20

1.1.8.1 Structural Response Models 1.1.20

1.1.8.2 Incremental Damage Accumulation 1.1.21

1.1.8.3 Analysis of Trial Design 1.1.21

1.1.9 EVALUATION OF EXISTING PAVEMENTS FOR REHABILITATION...1.1.22

1.1.10 IDENTIFICATION OF FEASIBLE REHABILITATION STRATEGIES...1.1.23

1.1.11 DESIGN OF REHABILITATION PROJECTS 1.1.24

1.1.12 DESIGN RELIABILITY 1.1.24
1.1.13 IMPLEMENTATION OF THE GUIDE WITHIN AN AGENCY 1.1.29
REFERENCES 1.1.31

PART 2—DESIGN INPUTS

CHAPTER 1: SUBGRADE/FOUNDATION DESIGN INPUTS 2.1.1

2.1.1 CHARACTERIZATION OF THE PAVEMENT FOUNDATION 2.1.1

2.1.2 SUBSURFACE CHARACTERIZATION FOR PAVEMENT DESIGN 2.1.2

2.1.2.1 Subsurface Exploration..2.1.3

2.1.2.2 Boring Location and Depth..2.1.5

2.1.2.3 Number or Spacing of Borings 2.1.5

2.1.2.4 Depth of Borings..2.1.5

2.1.2.5 Type of Samples and Sample Recovery 2.1.6

2.1.3 LABORATORY TESTING OF SUBGRADE SOILS 2.1.7

2.1.3.1 Number of Test Specimens..2.1.7

2.1.3.2 Types of Laboratory Tests 2.1.8

2.1.3.3 Condition of Resilient Modulus Laboratory Test Specimens.............2.1.11

2.1.3.4. Selection of In Situ Resilient Modulus for Soil Strata.......................2.1.12

2.1.3.5 Reporting of Test Results..2.1.13

2.1.4 IDENTIFICATION AND TREATMENT OF SPECIAL SUBSURFACE CONDITIONS 2.1.14

2.1.4.1 Compressible Soils..2.1.15

2.1.4.2 Swelling Soils 2.1.16

2.1.4.3 Subsurface Water 2.1.17

2.1.4.4 Frost-Susceptible Soils..2.1.18

2.1.5 FOUNDATION IMPROVEMENT AND STRENGTHENING 2.1.21

2.1.5.1 Stabilization 2.1.21

2.1.5.2 Thick Granular Layers 2.1.25

2.1.5.3 Subsurface Drainage 2.1.28

2.1.5.4 Geosynthetics..2.1.28

2.1.5.5 Soil Encapsulation 2.1.35

REFERENCES 2.1.37

CHAPTER 2: MATERIAL CHARACTERIZATION..2.2.1

2.2.1 INTRODUCTION 2.2.1

2.2.1.1 Material Factors Considered 2.2.2

2.2.1.2 Material Categories 2.2.5

2.2.1.3 Hierarchical Input Approach Concepts 2.2.7

2.2.2 INPUT CHARACTERIZATION FOR THE ASPHALT MATERIALS GROUP 2.2.8

2.2.2.1 Layer Modulus for New or Reconstruction Design 2.2.8

2.2.2.2 Layer Modulus for Rehabilitation Design 2.2.25

2.2.2.3 Poisson's Ratio for Bituminous Materials 2.2.28

2.2.2.4 Other HMA Material Properties 2.2.31

2.2.3 INPUT CHARACTERIZATION FOR THE PCC MATERIALS 2.2.34

2.2.3.1 Modulus of Elasticity of PCC Materials 2.2.34

2.2.3.2 Poisson's Ratio of PCC Materials..2.2.42

2.2.3.3 Flexural Strength of PCC Materials...2.2.43

2.2.3.4 Indirect Tensile Strength of PCC Materials...2.2.48

2.2.3.5 Compressive Strength of PCC Materials 2.2.51

2.2.3.6 Unit Weight of PCC Materials..2.2.51

2.2.3.7 PCC Coefficient of Thermal Expansion 2.2.52

2.2.3.8 PCC Shrinkage..2.2.54

2.2.3.9 PCC Thermal Conductivity, Heat Capacity, and Surface Absorptivity 2.2.57

2.2.4 INPUT CHARACTERIZATION FOR THE CHEMICALLY STABILIZED MATERIALS GROUP 2.2.57

2.2.5 INPUT CHARACTERIZATION FOR THE UNBOUND GRANULAR MATERIALS AND SUBGRADE MATERIALS GROUP 2.2.64

2.2.5.1 Pavement Response Model Unbound Material Inputs.........................2.2.66

2.2.5.2 EICM Inputs Unbound Materials...2.2.71

2.2.5.3 Other Unbound Materials 2.2.73

2.2.6 INPUT CHARACTERIZATION FOR BEDROCK MATERIALS..2.2.73

2.2.6.1 Modulus of Elasticity of Bedrock Materials....................................2.2.73
2.2.6.2 Poisson's Ratio of Bedrock Materials...2.2.74
2.2.7 OTHER MATERIALS CONSIDERATIONS...2.2.75
2.2.7.1 Consideration of Erodibility in Design (JPCP and CRCP Only).........2.2.75
REFERENCES……………………………………………………………………2.2.82

CHAPTER 3: ENVIRONMENTAL EFFECTS 2.3.1
2.3.1 INTRODUCTION 2.3.1
2.3.1.1 Importance of Climate in Mechanistic Empirical Design.....................2.3.1
2.3.1.2 Consideration of Climatic Effects in Design 2.3.2
2.3.1.3 Major Outputs of the EICM..2.3.5
2.3.1.4 Chapter Organization...2.3.7
2.3.2 CLIMATIC AND MATERIAL INPUTS REQUIRED TO MODEL THERMAL AND MOISTURE CONDITIONS..2.3.7
2.3.2.1 General Information...2.3.8
2.3.2.2 Weather-Related Data...2.3.9
2.3.2.3 Groundwater Table Depth...2.3.10
2.3.2.4 Drainage and Surface Properties..2.3.10
2.3.2.5 Pavement Structure Materials Inputs...2.3.12
2.3.3 EICM CALCULATIONS – COMPOSITE ENVIRONMENTAL EFFECTS ADJUSTMENT FACTOR, F_{env}, FOR ADJUSTING M_R................2.3.22
2.3.3.1 Relevance of F_{env} to Design 2.3.22
2.3.3.2 Environmental Effects on M_R of Unbound Pavement Materials.........2.3.23
2.3.3.3 Computation of Environmental Adjustment Factor, F_{env}.....................2.3.30
2.3.4 EICM CALCULATIONS – DETERMINATION OF THE TEMPERATURE THROUGHOUT THE PAVEMENT SYSTEM 2.3.38
2.3.4.1 Introduction...2.3.38
2.3.4.2 Boundary Conditions for CMS Model..2.3.41
2.3.4.3 Temperature Distribution Profile..2.3.45
REFERENCES 2.3.49

CHAPTER 4: TRAFFIC 2.4.1

2.4.1 INTRODUCTION 2.4.1

2.4.2 DESCRIPTION OF THE HIERARCHICAL APPROACH USED IN TRAFFIC CHARACTERIZATION..2.4.2

2.4.2.1 Level 1 Inputs – A Very Good Knowledge of Traffic Characteristics ..2.4.2

2.4.2.2 Level 2 Inputs – A Modest Knowledge of Traffic Characteristics........2.4.3

2.4.2.3 Level 3 Inputs – A Poor Knowledge of Traffic Characteristics 2.4.3

2.4.2.4 Summary 2.4.3

2.4.3 DESCRIPTION OF DATA SOURCES AND DATA ELEMENTS USED IN TRAFFIC CHARACTERIZATION 2.4.4

2.4.3.1 Traffic Load/Volume Data Sources 2.4.4

2.4.4 ASSUMPTIONS...2.4.6

2.4.5 INPUTS REQUIRED FOR TRAFFIC CHARACTERIZATION.................2.4.6

2.4.5.1 Traffic Volume – Base Year Information...2.4.7

2.4.5.2 Traffic Volume Adjustments 2.4.10

2.4.5.3 Axle Load Distribution Factors 2.4.19

2.4.5.4 General Traffic Inputs...2.4.26

2.4.6 INPUT PROCESSING 2.4.30

2.4.6.1 Step 1: Subdivide the Year into Traffic Seasons – Hours of the Day or Months of the Year with Similar Traffic Features 2.4.30

2.4.6.2 Step 2: Determine AADTT for the Base Year...................................2.4.30

2.4.6.3 Step 3: Determine the Normalized Truck Traffic Distribution...........2.4.31

2.4.6.4 Step 4: Determine the Number of Axles by Each Axle Type and Truck Class 2.4.31

2.4.6.5 Step 5: Determine the Normalized Axle Load Spectra for Each Axle Type...2.4.31

2.4.6.6 Step 6: Establish Traffic Growth/Decay Rates 2.4.31

2.4.6.7 Step 7: Predict Total Traffic – Future and Historical 2.4.31

2.4.6.8 Step 8: Determine the Axle and Tire Loading Details........................2.4.32

2.4.7 TRAFFIC SAMPLING PLAN FOR SITE SPECIFIC AVC AND WIM DATA 2.4.32
2.4.7.1 Sample Location – Location of Traffic Measurement Equipment 2.4.33
2.4.7.2 Sample Size and Frequency 2.4.33
REFERENCES 2.4.36

CHAPTER 5: EVALUATION OF EXISTING PAVEMENTS FOR REHABILITATION..2.5.1
2.5.1 INTRODUCTION 2.5.1
2.5.1.1 Major Aspects of Project-Level Pavement Evaluation..........................2.5.1
2.5.1.2 Definition of Project-Level Pavement Evaluation................................2.5.2
2.5.1.3 Level of Data Collection..2.5.4
2.5.1.4 Field Evaluation Plan..2.5.4
2.5.2 GUIDES FOR DATA COLLECTION...2.5.9
2.5.2.1 Overview...2.5.9
2.5.2.2 Data Required for Overall Condition Assessment and Problem Definition...2.5.10
2.5.2.3 Establishing Fundamental Analysis Segments 2.5.15
2.5.2.4 Distress Survey 2.5.21
2.5.2.5 Smoothness Measurements/Data 2.5.31
2.5.2.6 Surface Friction...2.5.34
2.5.2.7 Drainage Survey...2.5.35
2.5.2.8 Nondestructive Testing 2.5.35
2.5.2.9 Destructive Pavement Testing 2.5.54
2.5.3 OVERALL CONDITION ASSESSMENT AND PROBLEM DEFINITION...2.5.58
2.5.3.1 Structural Adequacy...2.5.59
2.5.3.2 Functional Adequacy 2.5.65
2.5.3.3 Drainage Adequacy...2.5.65
2.5.3.4 Material Durability..2.5.67
2.5.3.5 Maintenance Applications 2.5.71

2.5.3.6 Shoulders Adequacy 2.5.71
2.5.3.7 Variability Along the Project 2.5.72
2.5.3.8 Miscellaneous 2.5.72
2.5.4 SUMMARY 2.5.73
REFERENCES 2.5.75

PART 3—DESIGN ANALYSIS

CHAPTER 1: DRAINAGE..3.1.1

3.1.1 INTRODUCTION 3.1.1

3.1.2 GENERAL DESIGN CONSIDERATIONS FOR COMBATING MOISTURE 3.1.2

3.1.2.1 Prevent Moisture from Entering the Pavement System........................3.1.3

3.1.2.2 Provide Moisture-Insensitive (Nonerodible) Materials 3.1.4

3.1.2.3 Incorporate Design Features to Minimize Moisture Damage...............3.1.5

3.1.2.4 Removal of Free Moisture through Subsurface Drainage 3.1.6

3.1.3 SUBSURFACE DRAINAGE TERMINOLOGY...3.1.6

3.1.3.1 Permeable Base...3.1.6

3.1.3.2 Separator Layer...3.1.8

3.1.3.3 Edgedrains..3.1.9

3.1.3.4 Outlets...3.1.9

3.1.3.5 Headwall 3.1.9

3.1.3.6 Side Ditches 3.1.10

3.1.3.7 Storm Drains 3.1.10

3.1.3.8 Daylighting 3.1.10

3.1.4 SUBSURFACE DRAINAGE ALTERNATIVES.......................................3.1.10

3.1.4.1 Permeable Base System with Pipe Edgedrains: Type Ia 3.1.10

3.1.4.2 Daylighted Permeable Base System: Type Ib.....................................3.1.11

3.1.4.3 Nonerodible Base with Pipe Edgedrains: Type IIa.............................3.1.11

3.1.4.4 Nonerodible Base with Edgedrains and Porous Concrete Shoulder: Type IIb 3.1.12

3.1.4.5 Daylighted Dense-Graded Aggregate Base: Type III.........................3.1.13

3.1.5 SYSTEMATIC APPROACH FOR SUBSURFACE DRAINAGE DESIGN: CONSIDERATIONS IN NEW OR RECONSTRUCTED PAVEMENTS........3.1.13

3.1.5.1 Step 1: Assessing the Need for Drainage...3.1.14

3.1.5.2 Step 2: Selection of Drainage Alternatives..3.1.18

3.1.5.3 Step 3: Hydraulic Design...3.1.19

3.1.5.4. Step 4: Prepare Pavement Cross-Sections with Appropriate Drainage Features 3.1.23
3.1.5.5 Step 5: Perform Structural Design 3.1.23
3.1.6 SYSTEMATIC APPROACH FOR SUBSURFACE DRAINAGE DESIGN: CONSIDERATIONS FOR REHABILITATION PROJECTS 3.1.23
3.1.6.1 Step 1: Assessing the Need for Drainage........ 3.1.24
3.1.6.2 Step 2: Drainage Improvement Alternatives........ 3.1.25
3.1.6.3 Step 3: Hydraulic Design 3.1.28
3.1.6.4 Step 4: Prepare Pavement Cross-Sections with Appropriate Drainage Features 3.1.28
3.1.6.5 Step 5: Perform Structural Design 3.1.28
3.1.7 EDGEDRAIN MAINTENANCE........ 3.1.28
REFERENCES 3.1.30

CHAPTER 2: SHOULDERS........ 3.2.1
3.2.1 GEOMETRIC CONSIDERATIONS........ 3.2.1
3.2 2 STRUCTURAL DESIGN........ 3.2.2
3.2.2.1. Traffic Loadings on Shoulder 3.2.2
REFERENCES 3.2.5

CHAPTER 3: DESIGN OF NEW AND RECONSTRUCTED FLEXIBLE PAVEMENTS 3.3.1
3.3.1 INTRODUCTION 3.3.1
3.3.2 OVERVIEW OF FLEXIBLE PAVEMENT DESIGN PROCESS 3.3.2
3.3.2.1 Design Inputs 3.3.3
3.3.2.2 Pavement Response Models 3.3.6
3.3.2.3 Incremental Distress and Damage Accumulation........ 3.3.7
3.3.2.4 Distress Prediction 3.3.8
3.3.2.5 Smoothness (IRI) Prediction........ 3.3.12
3.3.2.6 Assessment of Performance and Design Modifications 3.3.12
3.3.2.7 Design Reliability 3.3.13

3.3.2.8 Life Cycle Costs Estimation 3.3.13
3.3.3 DESIGN INPUTS FOR NEW FLEXIBLE PAVEMENT DESIGN...........3.3.13
3.3.3.1 General Information..3.3.14
3.3.3.2 Site/Project Identification 3.3.15
3.3.3.3 Analysis Parameters..3.3.15
3.3.3.4 Traffic 3.3.18
3.3.3.5 Climate..3.3.25
3.3.3.6 Pavement Structure 3.3.27
3.3.4 FLEXIBLE PAVEMENT DESIGN PROCEDURE 3.3.37
3.3.4.1 Trial Design Parameters..3.3.38
3.3.4.2 Pavement Response Models 3.3.42
3.3.4.3 Performance Prediction..3.3.45
3.3.5 SPECIAL AXLE CONFIGURATION..3.3.106
3.3.6 CALIBRATION TO LOCAL CONDITIONS 3.3.107
3.3.6.1 Need for Calibration to Local Conditions....................................3.3.108
3.3.6.2 Approach to Calibration..3.3.109
REFERENCES 3.3.112

CHAPTER 4: DESIGN OF NEW AND RECONSTRUCTED RIGID PAVEMENTS 3.4.1
3.4.1 INTRODUCTION 3.4.1
3.4.2 OVERVIEW OF RIGID PAVEMENT DESIGN PROCESS 3.4.2
3.4.2.1 Design Inputs 3.4.2
3.4.2.2 Structural Response Model..3.4.7
3.4.2.3 Incremental Damage Accumulation 3.4.8
3.4.2.4 Distress Prediction 3.4.8
3.4.2.5 Smoothness (IRI) Prediction..3.4.13
3.4.2.6 Assessment of Performance and Design Modifications 3.4.13
3.4.2.7 Design Reliability 3.4.14
3.4.2.8 Life Cycle Costs Estimation 3.4.14
3.4.3 INPUTS FOR NEW RIGID PAVEMENT DESIGN 3.4.15

3.4.3.1 General Information 3.4.15
3.4.3.2 Site/Project Identification 3.4.15
3.4.3.3 Analysis Parameters 3.4.16
3.4.3.4 Traffic 3.4.17
3.4.3.5 Climate 3.4.23
3.4.3.6 Drainage and Surface Properties 3.4.28
3.4.3.7 Pavement Structure 3.4.29
3.4.3.8 Pavement Design Features 3.4.37
3.4.4 JPCP DESIGN CONSIDERATIONS 3.4.44
3.4.4.1 Slab Thickness 3.4.45
3.4.4.2 Slab Width 3.4.45
3.4.4.3 PCC Materials 3.4.45
3.4.4.4 Transverse Joint Spacing 3.4.46
3.4.4.5 Transverse Joint LTE 3.4.47
3.4.4.6 Transverse Joint Sawcut Depth 3.4.47
3.4.4.7 Longitudinal Joint Load Transfer and Ties 3.4.47
3.4.4.8 Longitudinal Joint Sawcut Depth 3.4.48
3.4.4.9 Base 3.4.48
3.4.4.10 Subbase 3.4.49
3.4.4.11 Subsurface Drainage 3.4.49
3.4.4.12 Shoulder Design 3.4.50
3.4.4.13 Subgrade Improvement 3.4.50
3.4.5 JPCP DESIGN PROCEDURE 3.4.50
3.4.5.1 JPCP Performance Criteria 3.4.50
3.4.5.2 Trial Design 3.4.51
3.4.5.3 Performance Prediction—Transverse Cracking 3.4.51
3.4.5.4 Performance Prediction—Faulting 3.4.69
3.4.5.5 Performance Prediction—Smoothness 3.4.87
3.4.6 CRCP DESIGN CONSIDERATIONS 3.4.99
3.4.6.1 Slab Thickness 3.4.99
3.4.6.2 Transverse Crack Width and Spacing 3.4.99

3.4.6.3 PCC Materials 3.4.100
3.4.6.4 Longitudinal Reinforcement 3.4.101
3.4.6.5 Depth of Longitudinal Reinforcement 3.4.101
3.4.6.6 Transverse Crack LTE 3.4.102
3.4.6.7 Slab Width 3.4.102
3.4.6.8 Transverse Reinforcement 3.4.102
3.4.6.9 Longitudinal Joint Load Transfer and Ties 3.4.101
3.4.6.10 Formed Depth of Longitudinal Joints 3.4.103
3.4.6.11 Base 3.4.103
3.4.6.12 Subbase 3.4.104
3.4.6.13 Subsurface Drainage 3.4.104
3.4.6.14 Shoulder Design 3.4.104
3.4.6.15 Subgrade Improvement 3.4.104
3.4.7 CRCP DESIGN PROCEDURE 3.4.105
3.4.7.1 CRCP Performance Criteria 3.4.105
3.4.7.2 Trial Design 3.4.106
3.4.7.3 Punchouts Prediction Model 3.4.106
3.4.7.4 CRCP Smoothness 3.4.130
3.4.8 SPECIAL LOADING SITUATIONS 3.4.133
3.4.9 CALIBRATION TO LOCAL CONDITIONS 3.4.134
3.4.9.1 Need for Calibration to Local Conditions 3.4.135
3.4.9.2 Approach to Calibration 3.4.136
3.4.9.3 Performance Prediction Models 3.4.138
REFERENCES 3.4.140

CHAPTER 5: IDENTIFICATION OF FEASIBLE REHABILITATION STRATEGIES 3.5.1
3.5.1 INTRODUCTION 3.5.1
3.5.1.1 Scope 3.5.1
3.5.1.2 Organization 3.5.2
3.5.2 MAJOR REHABILITATION STRATEGIES 3.5.2

3.5.2.1 Reconstruction with/without Lane Additions 3.5.3
3.5.2.2 Rehabilitation with Structural Overlay 3.5.3
3.5.2.3 Rehabilitation with Non-Structural Overlay 3.5.7
3.5.3 RECYCLING OF EXISTING PAVEMENT OR OTHER MATERIALS..... 3.5.9
3.5.4 IDENTIFICATION OF FEASIBLE REHABILITATION STRATEGIES 3.5.11
3.5.4.1 Steps 1 through 4—Determine Existing Pavement Condition and Causes of Distress and Identify All Possible Rehabilitation Constraints 3.5.13
3.5.4.2 Step 5—Selection of Major Rehabilitation Strategies and Rehabilitation Treatments 3.5.14
3.5.4.3 Step 6—Develop Preliminary Design of Feasible Rehabilitation Strategies 3.5.15
3.5.4.4 Step 7—Perform Life Cycle Cost Analysis for Possible Rehabilitation Strategies 3.5.19
3.5.4.5 Step 8—Determine Relevant Non-Monetary Factors that Influence Rehabilitation 3.5.19
3.5.4.6 Step 9—Determine Preferred Rehabilitation Strategy 3.5.20
3.5.5 SUMMARY 3.5.21
REFERENCES 3.5.23

CHAPTER 6—HMA REHABILITATION OF EXISTING PAVEMENTS 3.6.1
3.6.1 INTRODUCTION 3.6.1
3.6.1.1 Scope 3.6.1
3.6.1.2 Organization 3.6.2
3.6.2 OVERVIEW OF REHABILITATION DESIGN PROCESS 3.6.2
3.6.2.1 HMA Overlay of Existing HMA Surfaced Pavements 3.6.5
3.6.2.2 HMA Overlay of Fractured PCC Slabs 3.6.6
3.6.2.3 HMA Overlay of Existing Intact PCC Pavements 3.6.6
3.6.2.4 Reconstruction 3.6.7
3.6.3 INPUTS FOR HMA REHABILITATION DESIGN 3.6.7

3.6.3.1 General Information 3.6.11
3.6.3.2 Site/Project Identification 3.6.11
3.6.3.3 Analysis Parameters 3.6.12
3.6.3.4 Traffic 3.6.25
3.6.3.5 Climate 3.6.26
3.6.3.6 Pavement Structure 3.6.26
3.6.4 HMA OVERLAY OF EXISTING HMA SURFACED PAVEMENTS 3.6.28
3.6.4.1 Introduction 3.6.28
3.6.4.2 Subsurface Drainage Considerations 3.6.30
3.6.4.3 Pre-Overlay Treatments 3.6.30
3.6.4.4 Performance Criteria 3.6.32
3.6.4.5 Design Reliability 3.6.32
3.6.4.6 Characterization of Existing Pavement 3.6.32
3.6.4.7 Trial Section 3.6.43
3.6.4.8 Distress Prediction 3.6.44
3.6.4.9 Trial Design Performance Evaluation and Design Modifications 3.6.50
3.6.5 HMA OVERLAY OF FRACTURED SLAB 3.6.55
3.6.5.1 Introduction 3.6.55
3.6.5.2 Subsurface Drainage Considerations 3.6.55
3.6.5.3 Pre-Overlay Treatments 3.6.56
3.6.5.4 Performance Criteria 3.6.56
3.6.5.5 Design Reliability 3.6.56
3.6.5.6 Characterization of Existing Pavement 3.6.57
3.6.5.7 Trial Section 3.6.59
3.6.5.8 Distress Prediction 3.6.59
3.6.5.9 Trial Design Performance Evaluation and Design Modifications 3.6.61
3.6.6 HMA OVERLAY OF INTACT PCC PAVEMENT 3.6.62
3.6.6.1 Introduction 3.6.62
3.6.6.2 Subsurface Drainage Considerations 3.6.62
3.6.6.3 Pre-Overlay Treatments 3.6.62
3.6.6.4 Performance Criteria 3.6.64

3.6.6.5 Design Reliability 3.6.64
3.6.6.6 Characterization of Existing Pavement...3.6.65
3.6.6.7 Trial Section..3.6.68
3.6.6.8 Distress Prediction 3.6.68
3.6.6.9 Trial Design Performance Evaluation and Design Modifications 3.6.75
3.6.7 ADDITIONAL CONSIDERATIONS FOR REHABILIATION WITH HMA OVERLAYS...3.6.78
3.6.7.1 Shoulder Reconstruction...3.6.78
3.6.7.2 Lane Widening..3.6.78
3.6.7.3 Subdrainage Improvement 3.6.78
3.6.7.4 Pre-overlay Repairs of Concrete Pavements.......................................3.6.79
3.6.7.5 Pre-overlay Repairs of HMA Pavements..3.6.80
3.6.7.6 Reflection Crack Control 3.6.81
3.6.7.7 Cold In-Place Recycling 3.6.82
3.6.7.8 Hot In-Place Recycling...3.6.83
REFERENCES 3.6.85

CHAPTER 7: PCC REHABILITATION DESIGN OF EXISTING PAVEMENTS 3.7.1
3.7.1 INTRODUCTION 3.7.1
3.7.1.1 Background...3.7.1
3.7.1.2 Scope..3.7.1
3.7.1.3 Organization...3.7.2
3.7.2 OVERVIEW OF REHABILITATION DESIGN PROCESS.........................3.7.2
3.7.2.1 Concrete Pavement Restoration (CPR) of JPCP...................................3.7.4
3.7.2.2 Overlay Rehabilitation Options 3.7.6
3.7.3 DESIGN INPUTS FOR PCC REHABILITATION DESIGN 3.7.8
3.7.3.1 General Information..3.7.12
3.7.3.2 Site/Project Identification 3.7.13
3.7.3.3 Analysis Parameters..3.7.13
3.7.3.4 Traffic 3.7.13

3.7.3.5 Climate 3.7.14
3.7.3.6 Pavement Structure 3.7.14
3.7.3.7 Rehabilitation 3.7.36
3.7.4 JPCP REHABILITATION DESIGN 3.7.38
3.7.4.1 Performance Criteria 3.7.38
3.7.4.2 Design Reliability 3.7.39
3.7.4.3 Design Considerations 3.7.39
3.7.4.4 Trial Rehabilitation Design 3.7.41
3.7.4.5 Transverse Joint Faulting 3.7.41
3.7.4.6 Total Transverse Cracking (Bottom-Up and Top-Down)...................3.7.53
3.7.4.7 JPCP Smoothness...3.7.65
3.7.5 CRCP REHABILITATION DESIGN 3.7.69
3.7.5.1 Rehabilitation Design Considerations...3.7.69
3.7.5.2 Performance Criteria 3.7.74
3.7.5.3 Rehabilitation Trial Design 3.7.74
3.7.6 ADDITIONAL CONSIDERATIONS FOR REHABILITATION WITH PCC DESIGN (JPCP AND CRCP) 3.7.84
3.7.6.1 Shoulder Reconstruction 3.7.84
3.7.6.2 Lane Widening...3.7.85
3.7.6.3 Subdrainage Improvement 3.7.85
3.7.6.4 CPR/Pre-Overlay Repairs 3.7.84
3.7.6.5 Separator Layer Design for JPC and CRC Unbonded Overlays..........3.7.88
3.7.6.6 Joint Design (JPCP Overlays)..3.7.90
3.7.6.7 Reflection Crack Control for Bonded PCC over Existing JPCP/CRCP Overlays 3.7.91
3.7.6.8 Bonding (for Bonded PCC over Existing JPCP/CRCP Overlays) 3.7.91
3.7.6.9 Guidelines for Addition of Traffic Lanes 3.7.93
3.7.6.10 Guidelines for Widening of Narrow PCC Traffic Lanes/Slabs 3.7.94
3.7.6.11 Recycling 3.7.94
3.7.6.12 Local Calibration of PCC Rehabilitation..3.7.94
REFERENCES 3.7.95

PART 4—LOW VOLUME ROADS

CHAPTER 1: LOW VOLUME ROAD DESIGN..4.1.1

4.1.1 DESIGN PROCEDURES..4.1.1

4.1.1.1 Design Catalog...4.1.2

APPENDICES

APPENDIX A—GLOSSARY OF TERMS A.1

APPENDIX B—PAVEMENT STRATEGY SELECTION B.1

B.1 INTRODUCTION B.1

B.2 ENGINEERING CONSIDERATIONS B.1

B.3 TRAFFIC B.3

B.4 ENVIRONMENTAL CONSIDERATIONS B.3

B.5 CONSTRUCTION CONSIDERATIONS B.4

B.6 OTHER CONSIDERATIONS B.4

B.7 ECONOMIC CONSIDERATIONS (LIFE CYCLE COST ANALYSIS) B.6

APPENDIX C—LIFE CYCLE COST ANALYSIS GUIDELINES C.1

C.1 INTRODUCTION C.1

C.2 LCCA FRAMEWORK C.4

C.3 LCCA PROCESS C.14

C.4 LCCA 2002 SPREADSHEET PROGRAM C.52

C.5 EXAMPLE APPLICATIONS OF PROBABILISTIC LCCA C.53

C.6 GLOSSARY OF TERMS C.68

REFERENCES C.70

APPENDIX D—USER'S GUIDE – DESIGN GUIDE SOFTWARE AND DESIGN EXAMPLES D.1

D.1.INTRODUCTION TO THE DESIGN GUIDE SOFTWARE D.2

D.2 JPCP DESIGN EXAMPLE D.7

D.3 CRCP DESIGN EXAMPLE D.42

D.4 JPCP RESTORATION AND UNBONDED JPCP OVERLAY REHABILITATION DESIGN EXAMPLE D.79

D.5 CONVENTIONAL FLEXIBLE PAVEMENT DESIGN EXAMPLE D.105

D.6 AC OVER EXISTING AC REHABILITATION DESIGN EXAMPLE D.144

D.7 AC OVER EXISTING JPCP REHABILITATION DESIGN EXAMPLE....D.159

APPENDIX D. USER'S GUIDE—DESIGN GUIDE SOFTWARE AND DESIGN EXAMPLES

This appendix presents an introduction to the Design Guide software and guidance to perform pavement design using the software. Section D.1 in this appendix describes the main features of the Design Guide software and provides an introduction to the basic features of this software. Next, this appendix presents examples for pavement design using the Design Guide software. The following pavement types are considered in the design examples presented in Sections D.2 through D.7 respectively:

- New or reconstructed Jointed Plain Concrete Pavement (JPCP)
- New or reconstructed Continuously Reinforced Concrete Pavement (CRCP)
- JPCP Rehabilitation – JPCP Restoration and Unbonded JPCP overlay on an existing JPCP
- New or reconstructed asphalt concrete (AC) pavement
- AC Rehabilitation – AC overlay on existing AC
- AC Rehabilitation – AC on existing JPCP

The design examples in this section illustrate the use of all design inputs discussed in PART 2 of this Guide and the pavement design procedure described in PART 3, Chapter 3, 4, 6 and 7. The design examples chosen cover a wide range of input types and input levels. Each example is introduced with a detailed problem statement that summarizes the available data to begin the design process.

The new AC design and the new rigid design examples are presented with a detailed listing of the design requirements and constraints followed by a step-by-step description of the design procedure. Appropriate screen shots of the design software are also provided to guide the user with the design procedure. Other examples provide less detailed information.

It is required for the user to be familiar with the procedure for the design of new pavements before attempting to perform the design of a rehabilitated pavement. The use of the Design Guide software and the procedure to provide design inputs are similar for both new and rehabilitation designs. Therefore, for rehabilitation design, the Guide explains in detail only those aspects that are exclusively of relevance to rehabilitation design.

The Design Guide software program accompanying the Guide contains the design examples discussed in this appendix for the benefit of users gaining familiarity with this design procedure. Additional rehabilitation design options are also included.

D.1 INTRODUCTION TO THE DESIGN GUIDE SOFTWARE

The Design Guide is based on a mechanistic-empirical design procedure. The design procedure mechanistically calculates pavement responses such as stresses, strains, and deflections and lets the designer project the damage that will accumulate over time. Next, the procedure empirically relates damage over time to pavement distresses chosen by the designer. The procedure is shown in the flowchart in Figure D. 1. The design procedure is integrated into the Design Guide software.

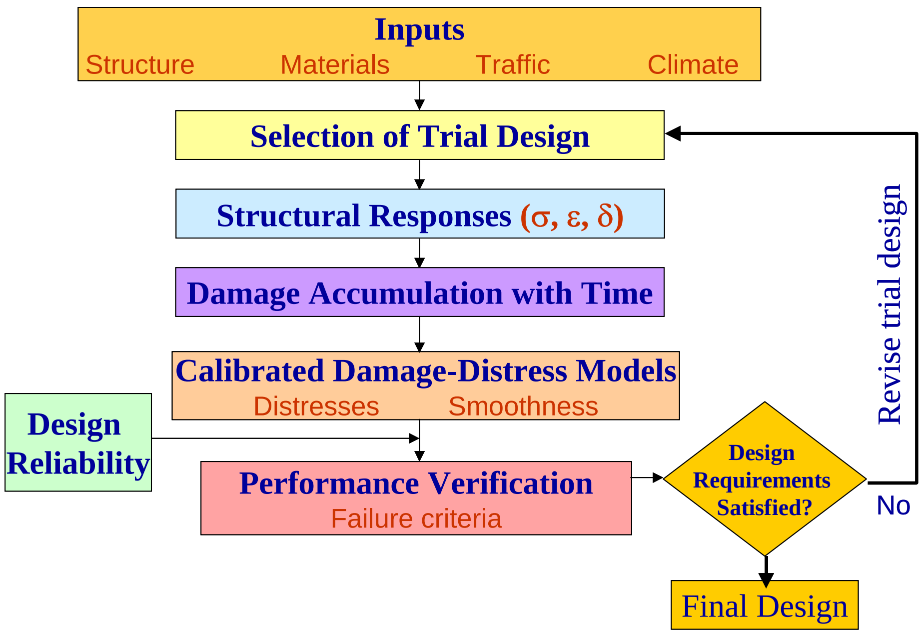


Figure D. 1. Design Guide procedure.

Pavement design using the Design Guide is an iterative process and includes the following steps:

1. The designer inputs a trial design.
2. The software estimates the damage and key distresses over the design life.
3. The design is verified against the performance criteria at a desired level of reliability. The design may be modified as needed to meet performance and reliability requirements.

The software provides:

1. An interface to input design variables,
2. Computational engines for analysis and performance prediction, and
3. Results and outputs from the analyses in formats suitable for use in electronic documents or for making hardcopies.

D.1.1 Installing Design Guide

The Design Guide installation CD uses the Windows auto-run feature. To install the software:

1. Start Windows.
2. Close any applications that are already running.
3. Inset the Design Guide CD into the CD-ROM drive.

If the installation does not start within a few seconds:

1. Double-click on My Computer icon on the Desktop.
2. Double-click on the Design Guide CD-ROM icon.
3. Run setup.exe.

Simply follow the on-screen directions to install Design Guide.

The default directory for installing the program files is C:\DG2002. The user is provided the option to change the installation directory. The installation program copies several files into the program root directory *DG2002*. *DG2002* will contain the main program file and several Dynamic Linked Libraries (DLL) that are necessary for the proper operation of the program. Other directories copied by the installation program are:

<u>Projects</u>: This directory contains the project files for all projects created by this release. All project files have the ".dgp" file extension. Other files that are used for inter-process communication and archiving purposes are kept in subdirectories of this directory. Each project has its own subdirectory.

<u>Bin</u>: This directory contains files necessary for the operation of the program. Don't delete, rename, or change any of the files from his directory.

<u>Defaults</u>: This directory contains default information files that are used by the program to generate default input values.

<u>HTML Help</u>: This directory contains the help files.

D.1.2 Uninstalling Design Guide

To uninstall the Design Guide software program:

1. Select the Windows Start button.
2. Select or move the mouse to Settings.
3. Select Control Panel.
4. Select Add/Remove Programs.
5. Uninstall the Design Guide software

D.1.3 Running Design Guide

During installation, a Design Guide program will be added to your Windows Start menu. To find Design Guide, click the Start button in the bottom left corner of your screen. Go up to the Programs option with your cursor to see a list of folders and programs. Select the Design Guide icon (the first icon shown below). Alternatively, the program can also be run by double-clicking the *DG2k2* icon on the desktop.

The software opens into a splash screen shown in Figure D. 2. A new file must be opened for each project, much like opening a new file for each document on a word processor. To open a new project, select "New" from the "File" menu of the tool bar. A typical layout of the program is shown below in Figure D. 3.

The user first provides the software with the General Information of the project and then inputs in three main categories, Traffic, Climate, and Structure. All inputs for the software program are color coded as shown in Figure D.4. Input screens that have not been visited are coded "red". Those that have default values are coded "yellow" and those that have complete inputs are coded "green".

Next, after all inputs are provided for the trial design, the user chooses to run the analysis. The software now executes the damage analysis and the performance prediction engines for the trial design input. The user can then view input and output summaries created by the program. The program creates a summary of all inputs of the trial design. It also provides a summary of the distress and performance prediction in both tabular and graphical formats. All charts are plotted in Microsoft Excel and hence can be incorporated into electronic documents and reports.

Figure D. 2. Design Guide software.

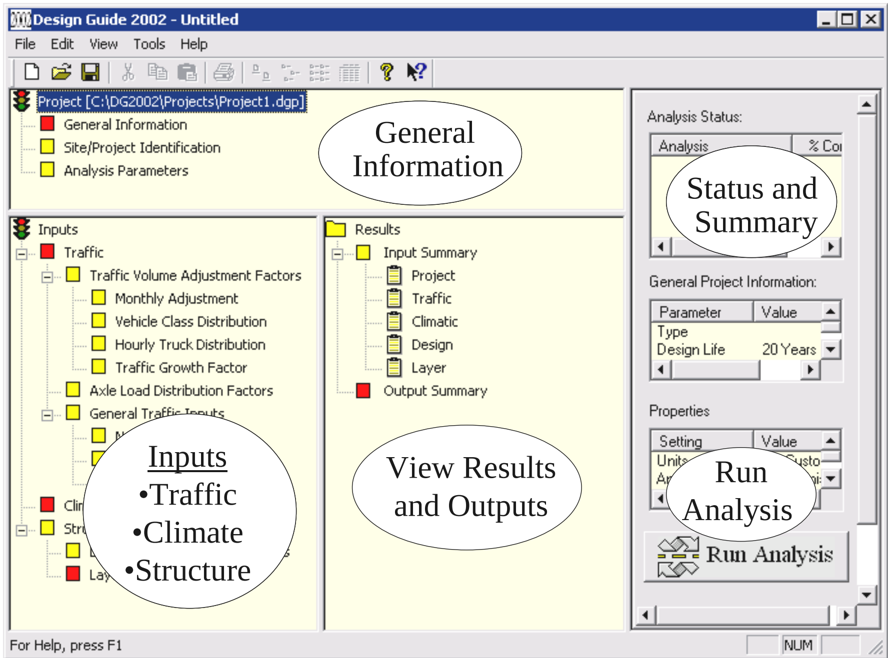


Figure D. 3. Program layout.

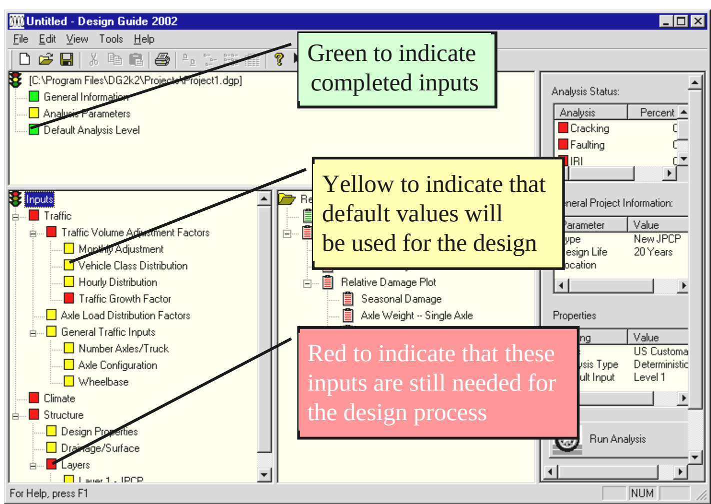


Figure D.4. Color-coded inputs.

The Design Guide software also offers extensive online help to users. Help is available in three levels.

1. Context sensitive and tool tip help as shown in Figure D. 5 and Figure D. 6 respectively. Context Sensitive Help (CSH) provides a brief definition of the input variable and its significance to the design. CSH can be accessed by right-clicking the mouse on an input variable. Tool tip help prompts the

typical range in values for each input and will be accessed with moving the cursor close to each input.

2. Html help (as in the level of help you are using now) provides the next level of help and is in more detail than level 1 help. It can be accessed by clicking on the “?” on the top right corner of the screen.
3. Link to detailed Design Guide documents.

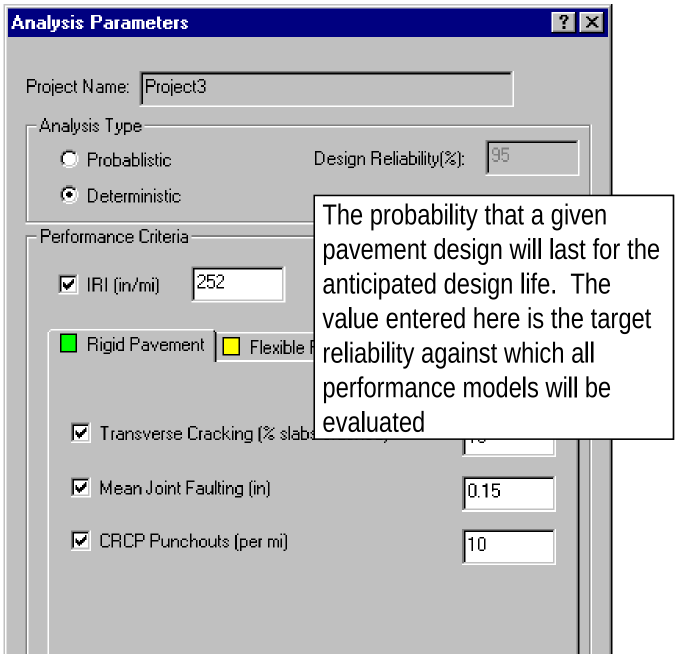


Figure D. 5. Context sensitive help.

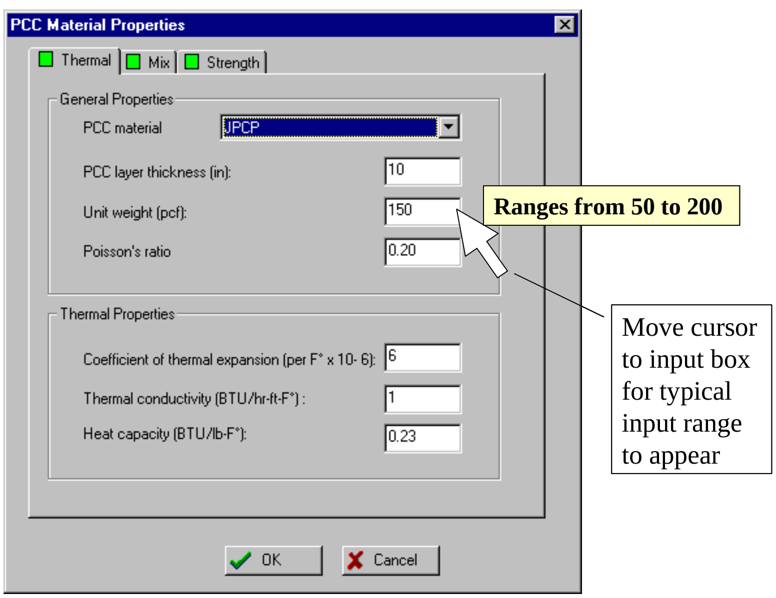


Figure D. 6. Tool tip help.

D.2. JPCP DESIGN EXAMPLE

Design Life

The jointed plain concrete pavement has a 25-year design life and will be constructed in the month of September 2002 to be opened to traffic in November 2002.

Construction Requirements

Assuming a good quality of construction, the pavement shall have an initial IRI between 50 and 75 in/mile (assume 63 in/mile for design purposes).

Analysis Parameters

It is expected that at the end of the 25-year design life, the pavement will have no more than 15 percent transverse cracking at 95 percent reliability level and no more than 0.15 inch faulting at a reliability level of 90 percent. In addition, the smoothness should be maintained at an IRI of less than 252 in/mile at a reliability level of 95 percent.

Location

The pavement is in the state of Illinois and in the east central region of the state. It is located in the close vicinity of Champaign Urbana. The 5-mile stretch of pavement to be designed is in the northbound lane called JPCP1 between mileposts 00 + 00 to 05+00.

Traffic

The two-way average annual daily truck traffic (AADTT) on this highway is estimated to be 2250 trucks during the first year of its service. There will be two lanes in the design direction with 90% of the trucks in the design lane. Truck traffic is equally distributed in both directions (i.e. 50% of the trucks drive in the design direction). The operational speed is 60 mph.

This pavement is being designed for heavy traffic in a principal arterial/Interstate category highway and therefore the traffic consists of a high percentage of single trailer trucks.

For each class of vehicle, the traffic pattern on monthly and daily bases remains the same through out the year. However, the traffic varies over a 24-hour period and is same as the national default based on LTPP data (provided in the Design Guide and the software).

After the base year, over the design life of the pavement, the traffic increases by 4.0 % of the preceding year’s traffic (compounded annually).

The axle load distribution is identical to the national defaults (derived from LTPP) provided with the Design Guide software for each vehicle class, axle type, load category, and months of the year.

Assume that the mean of the outer wheel edge is located 18 inches from the edge of the pavement. The truck lateral wander has a standard deviation of 10 inches. The pavement has a standard design lane width is 12 feet. The number of single, tandem, tridem and quad axles for each vehicle class is similar to the national defaults derived from LTPP (provided in the Design Guide and software).

The axle configuration is as follows:

> Average axle width (edge-to-edge outside dimensions, ft): 8.5
> Dual tire spacing (in): 12

The single and dual tire pressures are 120 psi. The design lane is 12 feet wide. The average axle spacing for tandem, tridem and quad axles are as follows:

Axle type	**Axle spacing (in)**
Tandem	51.6
Tridem	49.2
Quad	49.2

Drainage and Surface Properties

The geometric design of the highway calls for a cross slope of 2 percent. The drainage path will have a length of 12 feet from the centerline to the edge drain adjacent to the lane-shoulder joint, and the infiltration will depend on the chosen shoulder type and the presence of edge drains. Assume a surface shortwave absorptivity of 0.85 (used in all calibration).

JPCP Design Features

It is anticipated that the temperature and curing conditions will induce a permanent curl/warp equivalent to –10 deg F in this section if a curing compound is used during the curing process (this is the mean determined from calibration).

Concrete Mix Properties

Concrete mix design to be used in this project has level 1-strength tests for the concrete compressive strength, modulus of elasticity, and modulus of rupture. Tests have been performed at concrete ages of 7, 14, 28, and 90 days. Because a long-term strength test could not be performed, estimates of 20-year to 28-day strength and modulus ratios were provided as recommended in the Guide. The results from the laboratory tests are summarized as:

Time, days	f_c', psi	E_{PCC}, psi	MR, psi
7	6697	4553550	777
14	7320	4760907	813
28	7927	4954161	846
90	8895	5248021	896
20 yr to 28 day strength ratio	1.44	1.2	1.2

The coefficient of thermal expansion of the mix was found to be 6.3 in/in/deg F. Assume a thermal conductivity of 1.25 BTU/hr-ft-^{o}F and a specific heat of 0.28 BTU/lb-^{o}F. The unit weight and Poisson's ratio of the mix were 145 pcf and 0.20 respectively (used in calibration).

The concrete mix design comprised of Type 1 cement, with a cement content of 565 lb/cubic yard and a water cement ratio of 0.402. The aggregate type used for this mix design is dolomite. Shrinkage characteristics of the mix indicate that its reversible shrinkage is 50% of its ultimate shrinkage value and it takes 35 days to develop 50% of its ultimate shrinkage. The ultimate shrinkage is however not known.

Base Material

The base materials chosen in this design example include a cement stabilized base and a crushed stone layer. The cement stabilized base layer has a unit weight of 150 pcf, Poisson's ratio of 0.20, and an average elastic modulus of 1,789,845 psi. Assume a thermal conductivity of 1.25 BTU/hr-ft-^{o}F and a specific heat of 0.28 BTU/lb-^{o}F. The crushed stone base layer has a modulus of 40,000 psi and a PI of 1.0. Sieve analysis results of this material show that 10% and 80% of the material passes through the #200 and #4 sieve respectively. The D_{60} of the crushed stone material is 2 mm.

Subgrade

The subgrade in this location has an M_r value of 18,000 psi estimated at optimum moisture conditions. The plasticity index of the soil is 25. Assume default values for other subgrade inputs.

Trial Design

The Design Guide procedure is an iterative procedure that requires the user to develop a trial design to begin the design process. The trial design is analyzed over the design period specified by the designer. The trial design is then evaluated based on the design criteria and then suitably modified till a final design is achieved. The design process is integrated into the Design Guide software program.

The design process requires the following steps:

D.2.1 Create a New project

D.2.1.1 Create a new design project in the Design Guide program

Open the Design Guide program from the *Programs* menu of the operating system (windows 98, 2000, XP, NT). Next open a new file and assign a name to the project, "*JPCP*" as shown in Figure D.7. Next, select the folder to store the design files as "*C:\DG2002\Projects*". Select US Customary units as the measurement system by clicking the radio button adjacent to it. Next, click "*OK*" and the program opens the main layout screen of the design project as shown in Figure D.8.

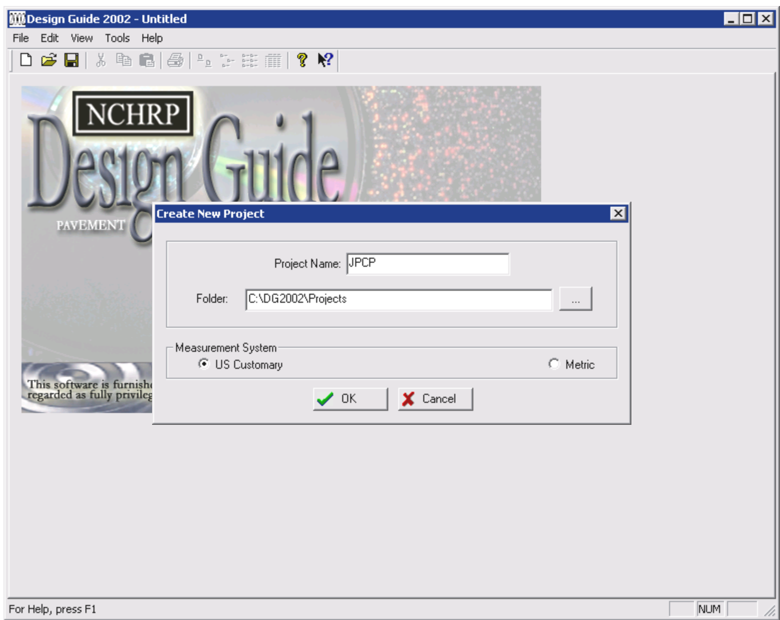


Figure D.7. Create a New Project File from the Main Program.

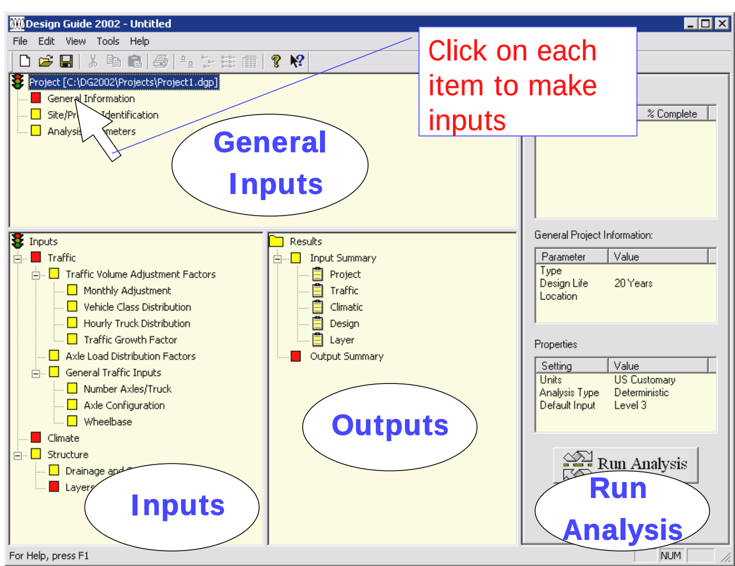


Figure D.8. Main program layout.

D.2.2 General Inputs

D.2.2.1 *General Information*

On the main project screen click on the *General Information* input to open the *General Information* screen. Inputs on General Information Screen as shown in Figure D.9:

Design Life: 25 years
Pavement Construction Month: September 2002
Traffic Open Month: November 2002
Type of Design: New Pavement – Jointed Plain Concrete Pavement (JPCP)

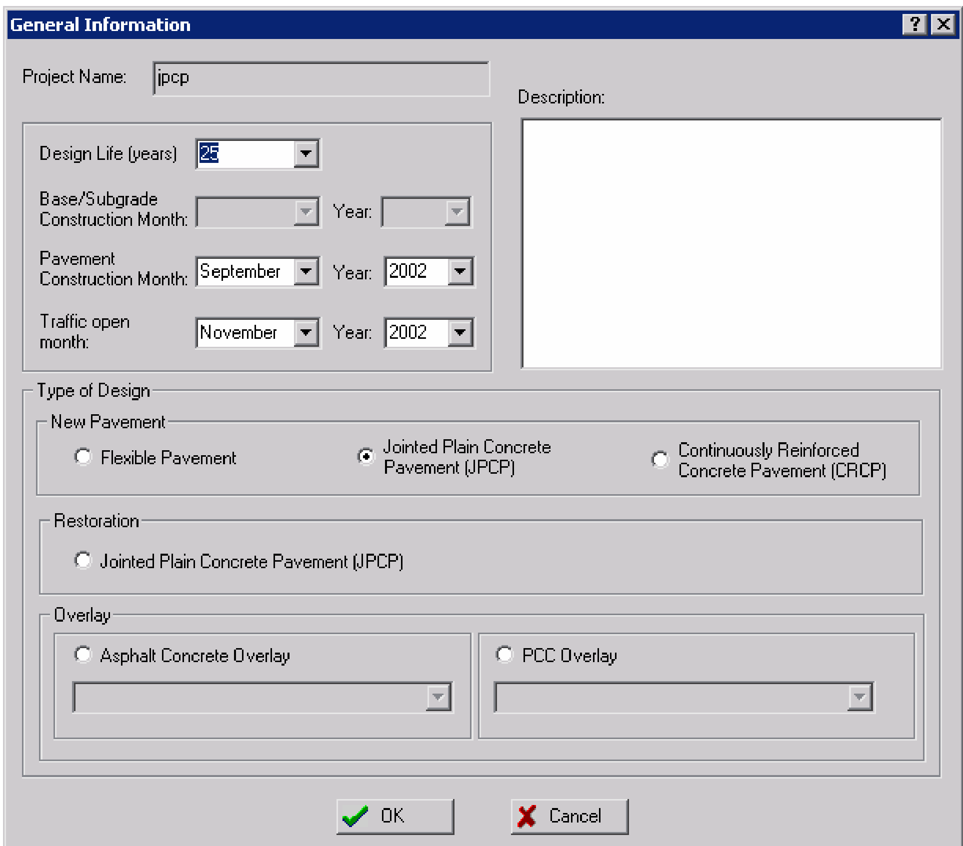


Figure D.9. *General Information* screen.

Click *OK* and return to the program layout screen

D.2.2.2 *Site/Project Identification*

Click on *Site/Project Identification* to open the *Site/Project Identification* screen. Inputs made on this screen are purely for providing identification to the project. Inputs to be provided for this design, as shown in Figure D.10, are:

Location: Illinois
Project ID: JPCP Design Example
Section ID: JPCP1
Functional Class (from pull-down menu): Principal Arterials – Interstate and Defense
Date: Date performing the design
Station/milepost format: 00+00
Station/milepost begin: 00 + 00
Station/milepost end: 05 + 00
Traffic Direction: Northbound

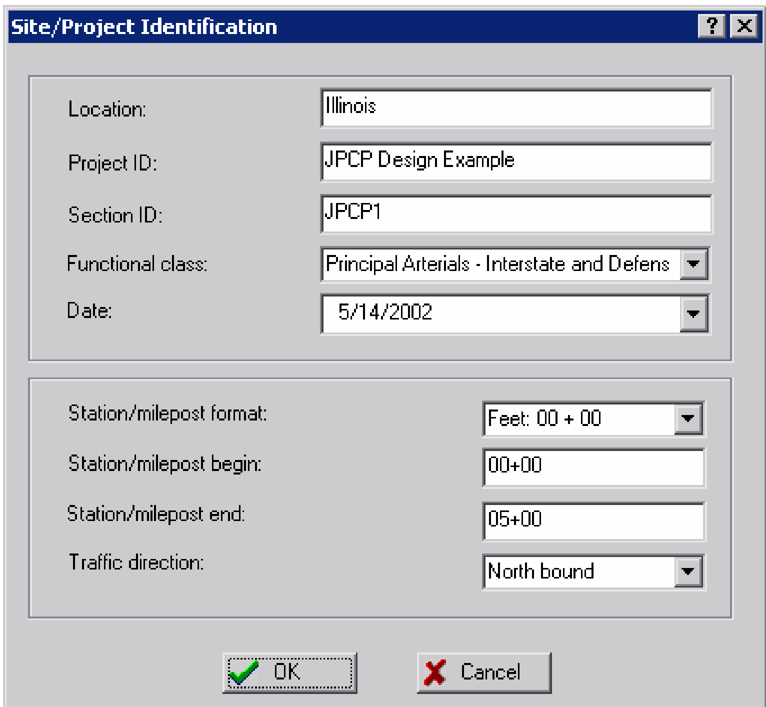


Figure D.10. *Site/Project Identification* screen.

Click *OK* and return to the main layout program.

D.2.2.3 *Analysis Parameters*

This screen allows the user to make inputs with regard to design criteria chosen by the agency. For this specific example, the inputs to be made on the *Analysis Parameters* screen, as show in Figure D.11 are as follows:

Initial IRI (in/mile): 63
Analysis Type: Probabilistic
Performance Criteria
Terminal IRI (in/mile): 252

Reliability (%, for IRI criteria): 95
Transverse Cracking (% slabs cracked): 15
Reliability (%, for transverse cracking): 95
Mean Joint Faulting (in): 0.15
Reliability (%, for faulting): 90

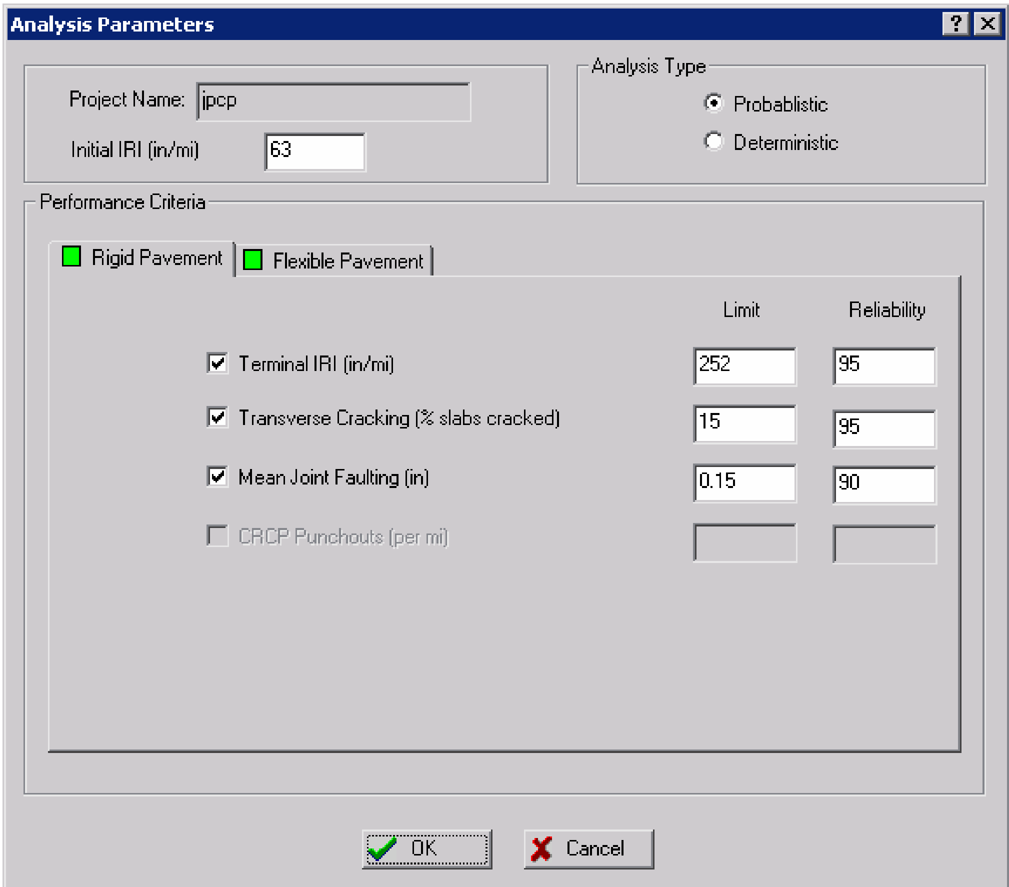


Figure D.11. *Analysis Parameters* screen for JPCP.

Click *OK* and return to the main layout program. Note that the icons in the general inputs are all green at this point. It is suggested that at this point, the input file be saved by clicking on the diskette icon in the tool bar or by clicking *Save* on the *File* menu.

D.2.3 Traffic Inputs

D.2.3.1 *Traffic*

This screen allows the user to make general traffic volume inputs and also provides a link to other traffic screens for Volume Adjustments, Axle Load Distribution Factors, and General Inputs. Please note that these screens can also be accessed from the main layout screen. Inputs on this screen, as shown in Figure D. 12 are as follows:

Two way average annual truck traffic: 2250
Number of lanes in design direction: 2
Percent of trucks in design direction: 50
Percent of trucks in design lane: 90
Operational truck speed: 60

Note that the chosen design life and the date of opening to traffic appear on this screen. Also note the links to *Traffic Volume Adjustment*, *Axle Load Distribution*, and *General Traffic Inputs* screens. These are the three main categories of traffic inputs required for the design and individual links to these screens are also available from the main program layout.

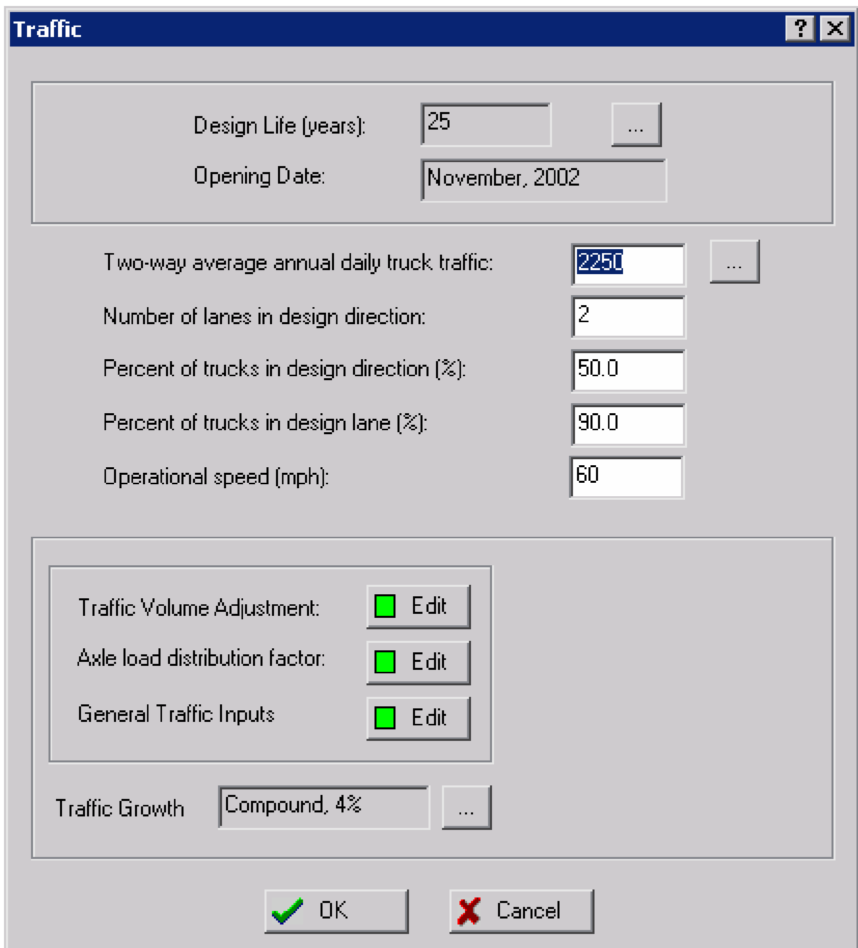


Figure D. 12. *Traffic* screen.

Click *OK* and return to the main layout program.

D.2.3.2. *Traffic Volume Adjustment Factors*

The Traffic Volume Adjustment Factors screen has 4 property pages (or sub-screens), namely:

- *Monthly Adjustment*
- *Vehicle Class Distribution*
- *Hourly Distribution*
- *Traffic Growth Factors*

D.2.3.2.1 *Monthly Adjustment*

The inputs on this screen indicate the distribution of traffic over the different months of a year for each traffic class. The Monthly Adjustment Factor (MAF) is the proportion of AADTT occurring over a 24-hour period in each month for each vehicle class.

For this example, since the traffic distribution remains the same through out the year, i.e. does not change between the different months of the year, the default monthly adjustment factors can be used.

Click on the radio button for Level 3 default inputs as shown in Figure D.13. Note that the default MAF value is 1.0 for all months in each vehicle class.

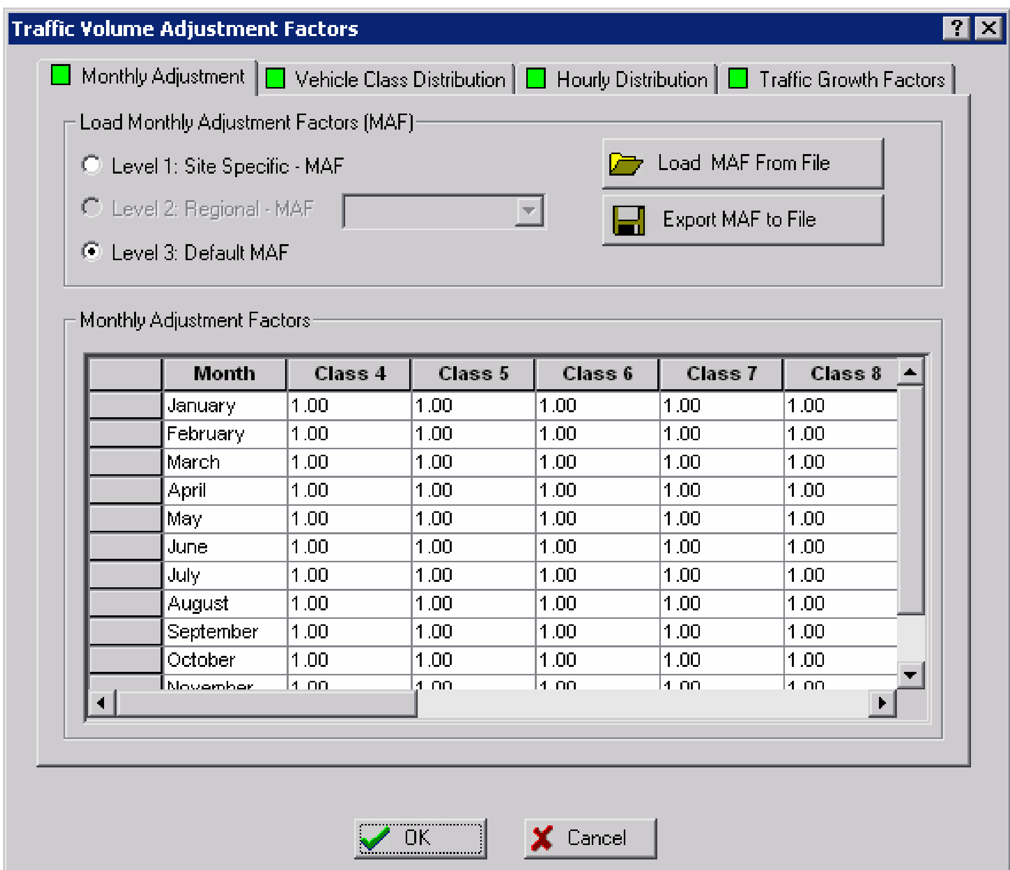


Figure D.13. *Monthly Adjustment Factors* screen.

Next click on the *Vehicle Class Distribution* tab.

D.2.3.2.2 *Vehicle Class Distribution*

Site-specific vehicle class distribution data is available for this design project. Click on the radio button *Level 3: Default Distribution* and click on the *Load Default Distribution* button. Select pavement category as *Principal/Arterials-Interstate and Defense* and choose Truck Traffic Classification (TTC) #2 listed in the 11th row of the table as shown in Figure D. 14. This *TTC* has a high percentage of vehicles in Class 9 (single trailer trucks).

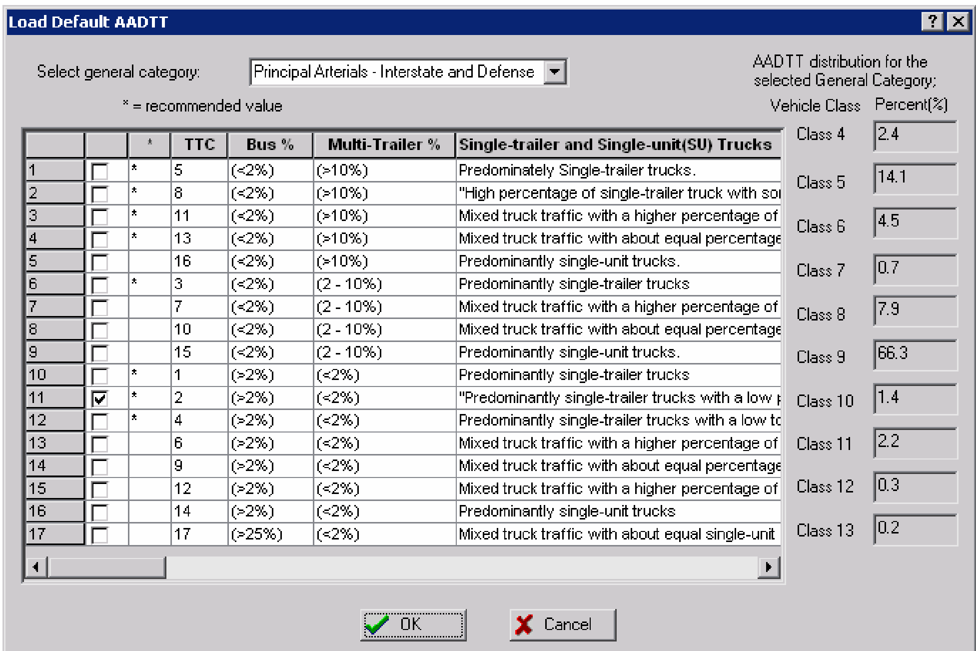


Figure D. 14. *Load Default AADTT* screen.

Click *OK* and return to the *Vehicle Class Distribution* screen. As shown in Figure D. 15, the TTC 2 distribution by vehicle class is seen on the screen. Next, click on the *Hourly Distribution* tab.

D.2.3.2.3 *Hourly Distribution*

Enter the hourly distribution of the AADTT as shown in Figure D.16. Next, click on the *Traffic Growth Factors* tab.

D.2.3.2.4 *Traffic Growth Factors*

The given data suggests that the traffic grows 4.0% at a compound rate. The program will use a default function for traffic growth at a compound rate. Select *Compound Growth* and enter a growth rate of 4.0% as shown in Figure D.17.

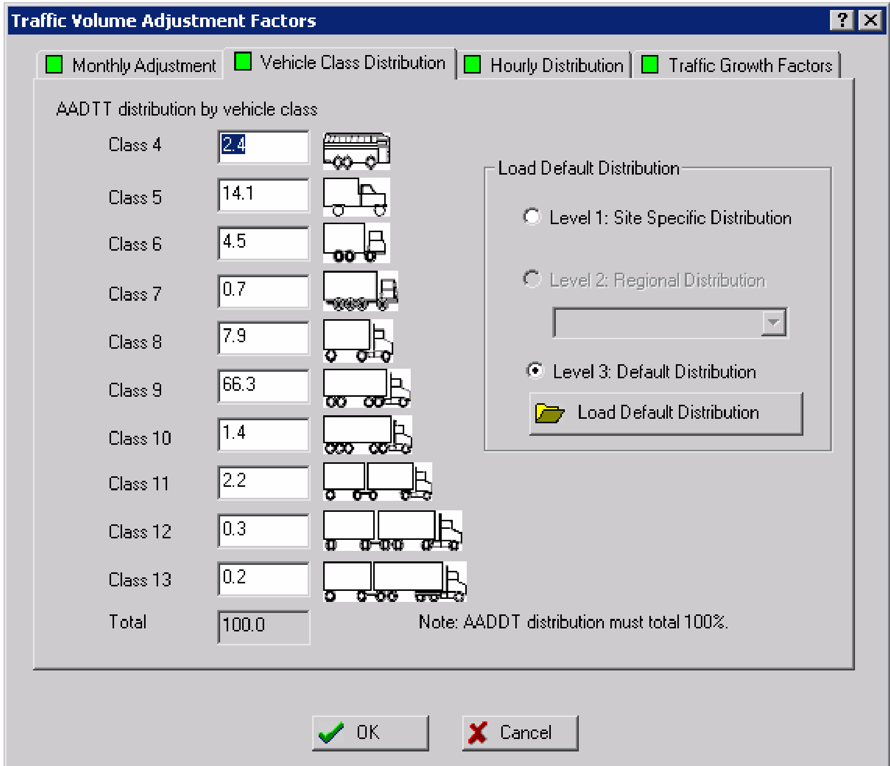


Figure D. 15. *Vehicle Class Distribution* screen.

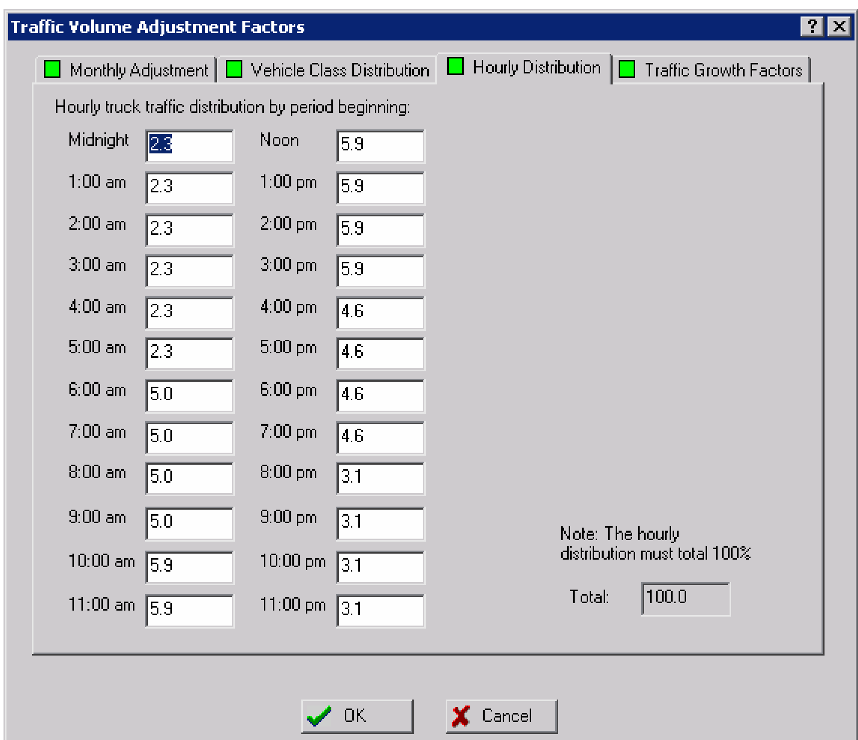


Figure D.16. *Hourly Distribution* screen.

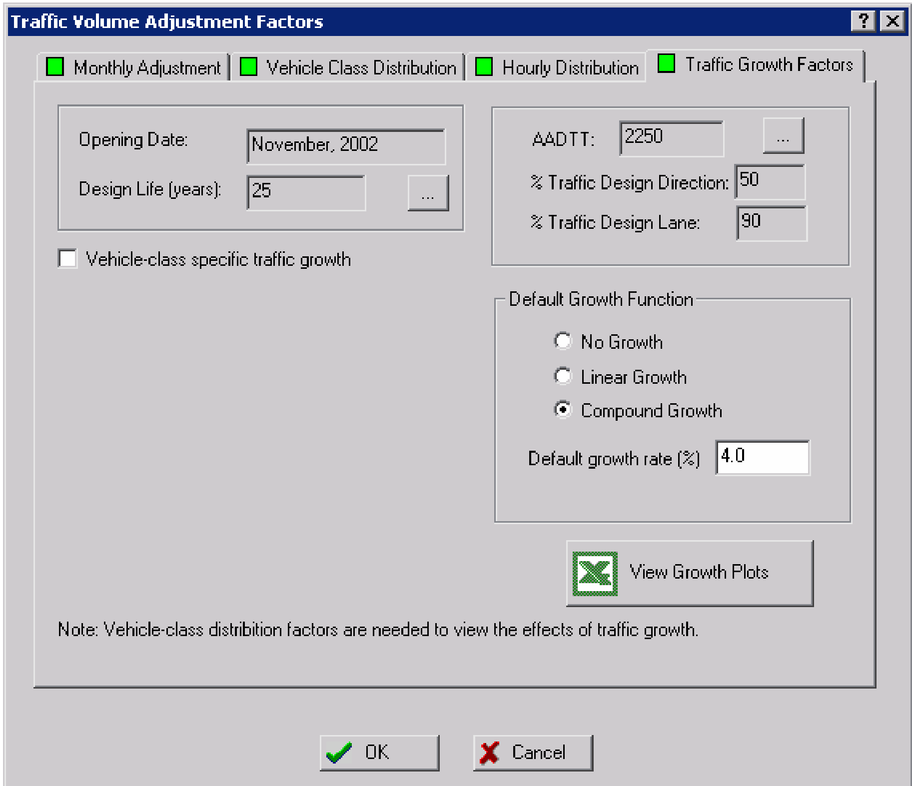


Figure D.17. *Traffic Growth Factors* screen.

Next click on *View Growth Plots* to open a Microsoft Excel spreadsheet that shows the growth in AADTT for each vehicle class over the design life. The plots are shown in Figure D.18, Figure D.19, and Figure D.20.

Close the Excel spreadsheet and click *OK* on the *Volume Adjustments* screen to return to the main layout page.

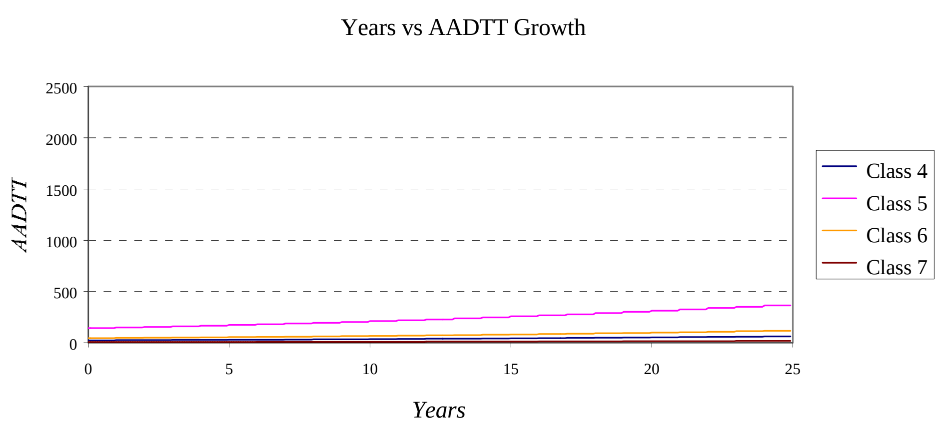


Figure D.18. Growth in AADTT for Vehicle classes 4 through 7.

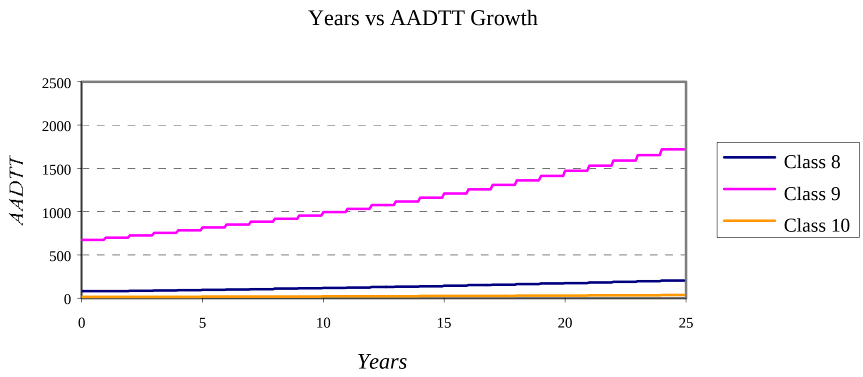


Figure D.19. Growth in AADTT for Vehicle classes 8 through 10.

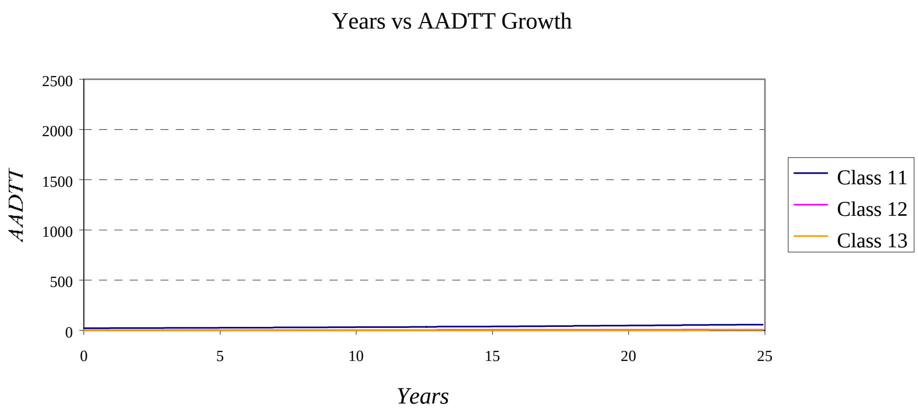


Figure D.20. Growth in AADTT for Vehicle classes 11 through 13.

D.2.3.3 *Axle Load Distribution Factors*

This screen allows the user to specify the percentage of vehicles in each vehicle class, at each load level, for each axle type. This design example uses the default LTPP distribution and therefore the level 3-default input will be used. Click on the radio button for level 3 axle load distribution factors as shown in Figure D. 21. The program automatically loads default values for these inputs. Click *Ok* to return to the main screen.

Note that the program also allows exporting a previously saved file if the user so chooses.

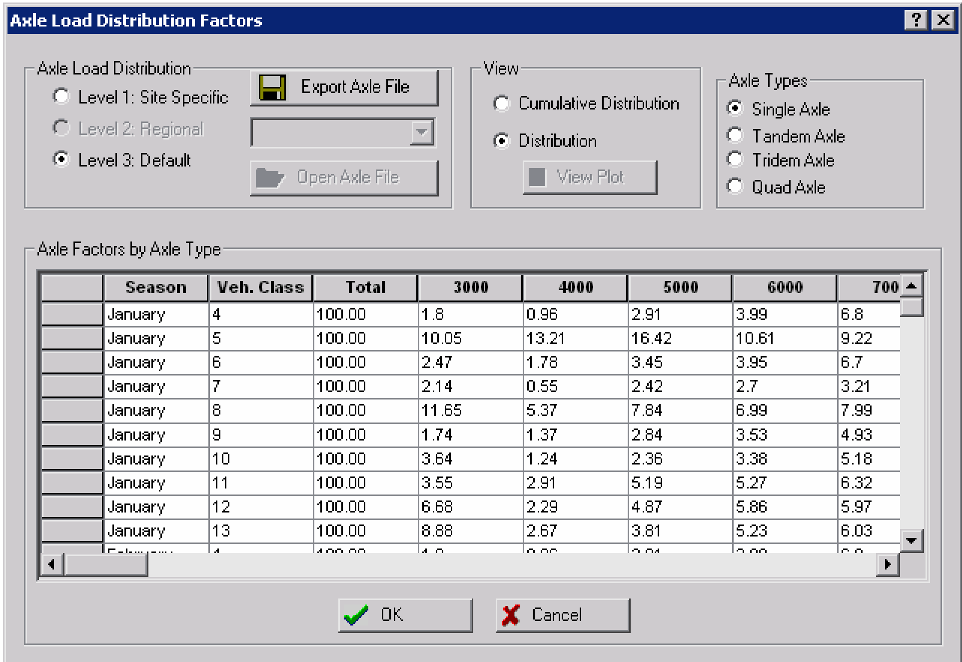


Figure D. 21. Axle Load Distribution Factors screen.

D.2.3.4 *General Traffic inputs*

This screen allows the user to provide traffic wander inputs and also has 3 property pages, namely,

> *Number of Axles/Truck*
> *Axle Configuration*
> *Wheelbase*

Enter the following inputs with regard to lateral traffic wander as shown on Figure D. 22
Mean wheel location: 18 inch
Traffic wander standard deviation: 10
Design lane width: 12 feet

D.2.3.4.1 *Number Axles/Truck*

Enter the number of axles per truck as shown in Figure D. 22:

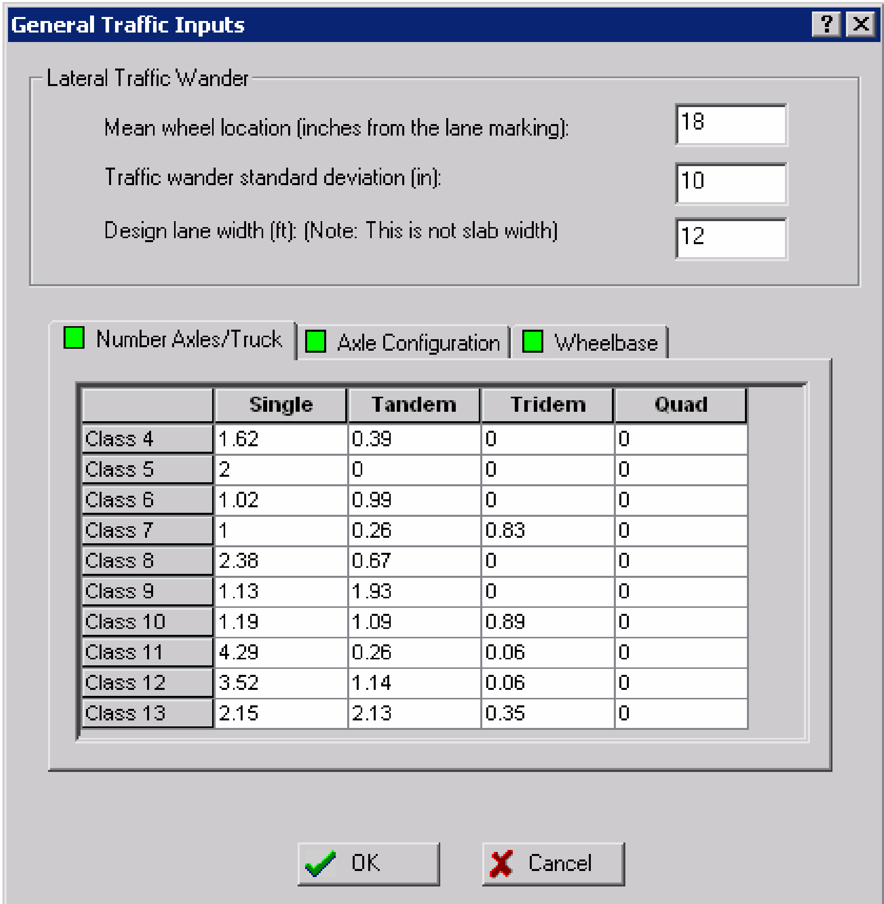


Figure D. 22. *General Traffic* Inputs – *Number of Axles/Truck* screen.

D.2.3.4.2 *Axle Configuration*

Enter the following inputs on the *Axle Configuration* property page as shown in Figure D. 23:

Average axle width: 8.5 feet
Dual tire spacing: 12 in
Tire pressure:
- Single tire: 120 psi
- Dual tire: 120 psi

Axle spacing:
- Tandem axle: 51.6 in
- Tridem axle: 49.2 in
- Quad axle: 49.2 in

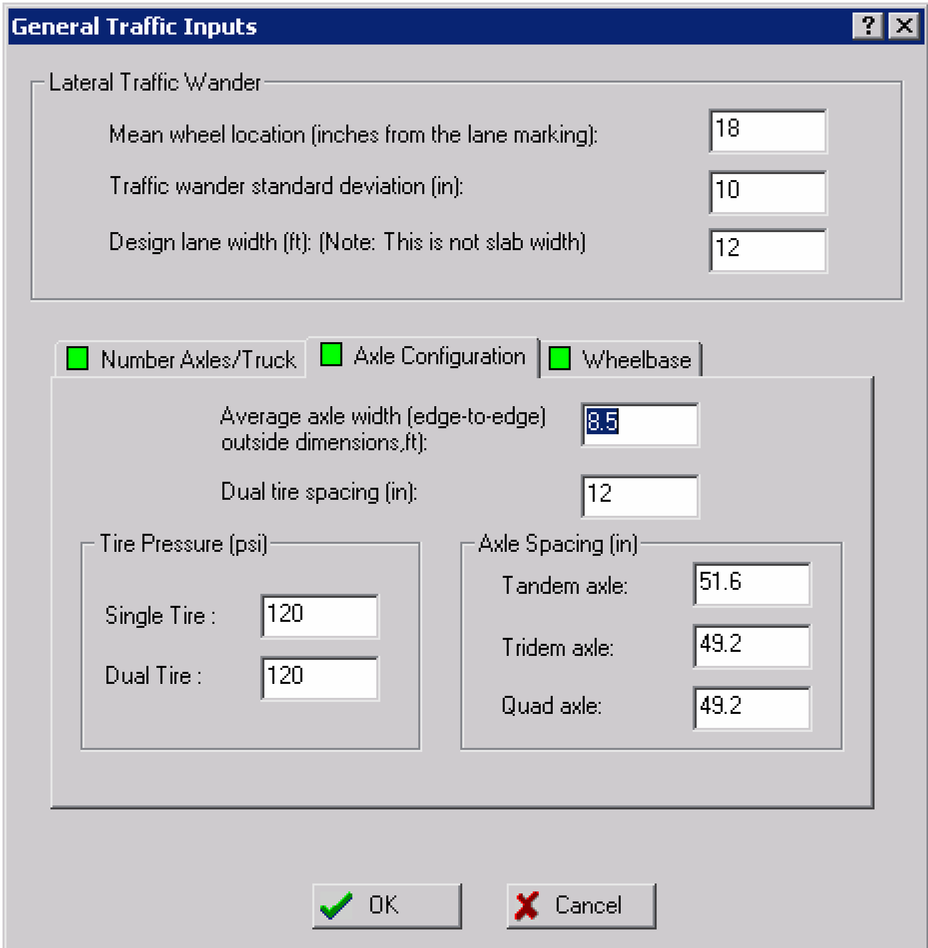


Figure D. 23. *General Traffic* Inputs – *Axle Configuration* screen.

<u>D.2.3.4.3 *Wheelbase*</u>

Enter the following inputs on the *Wheelbase* property page as shown in Figure D. 24:

- Average axle spacing
  - Short: 12 feet
  - Medium: 15 feet
  - Long: 18 feet
- Percentage trucks
  - Short: 2.0 percent
  - Medium: 20.0 percent
  - Long: 78.0 percent

Click *OK* and return to the main program layout screen. The user, by this stage, has made all traffic inputs and is now ready to make Climate inputs for the project. Save the project file before proceeding.

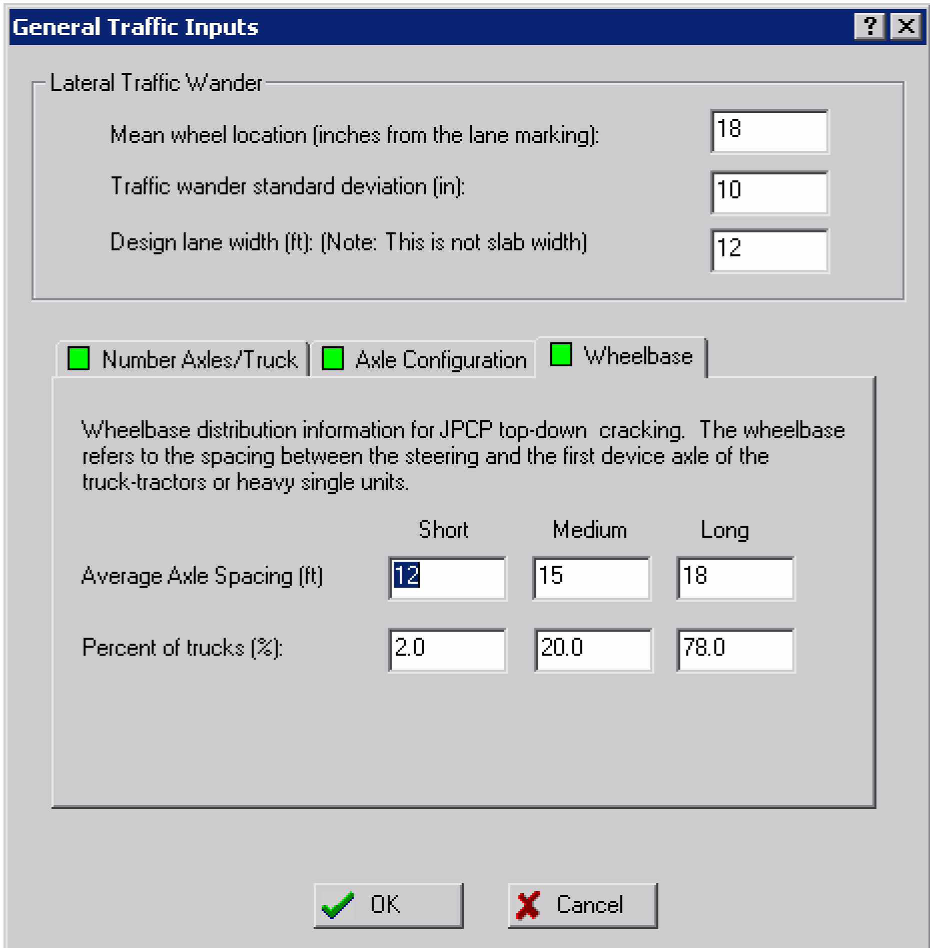


Figure D. 24. *General Traffic* Inputs – *Wheelbase* screen.

D.2.4 Climate Inputs

D.2.4.1 *Climate*

The project site is in the vicinity of Champaign Urbana, for which a climatic file exists in the ICM database. The user has to upload this climatic data for use in this design project so that the Design Guide software can predict the moisture and temperature gradients in trial designs.

Click on *Climate* on the main project layout screen. On the main *Climate* screen, as shown in Figure D. 25, click on *Generate* to generate a new climatic data file. Next, click on the radio button corresponding to *Climatic data for a specific weather station*. Choose Champaign-Urbana, IL from the scroll down list of weather stations with climatic data. Enter the *Depth of water table (feet)* as “10” and click on *Select station*.

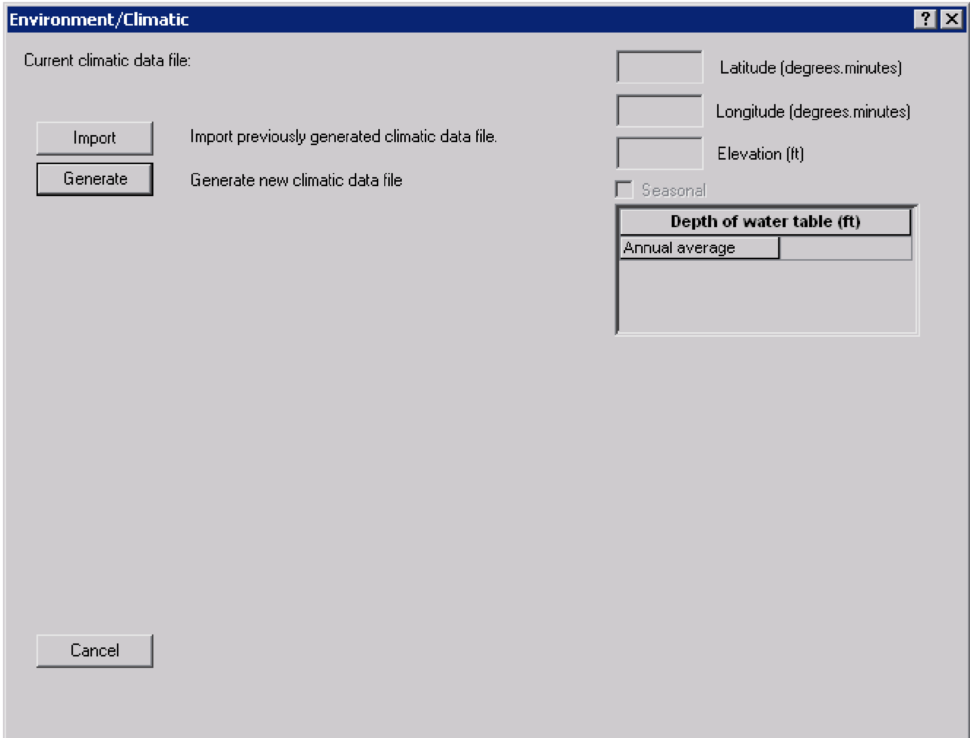


Figure D. 25. Main *Climate* screen.

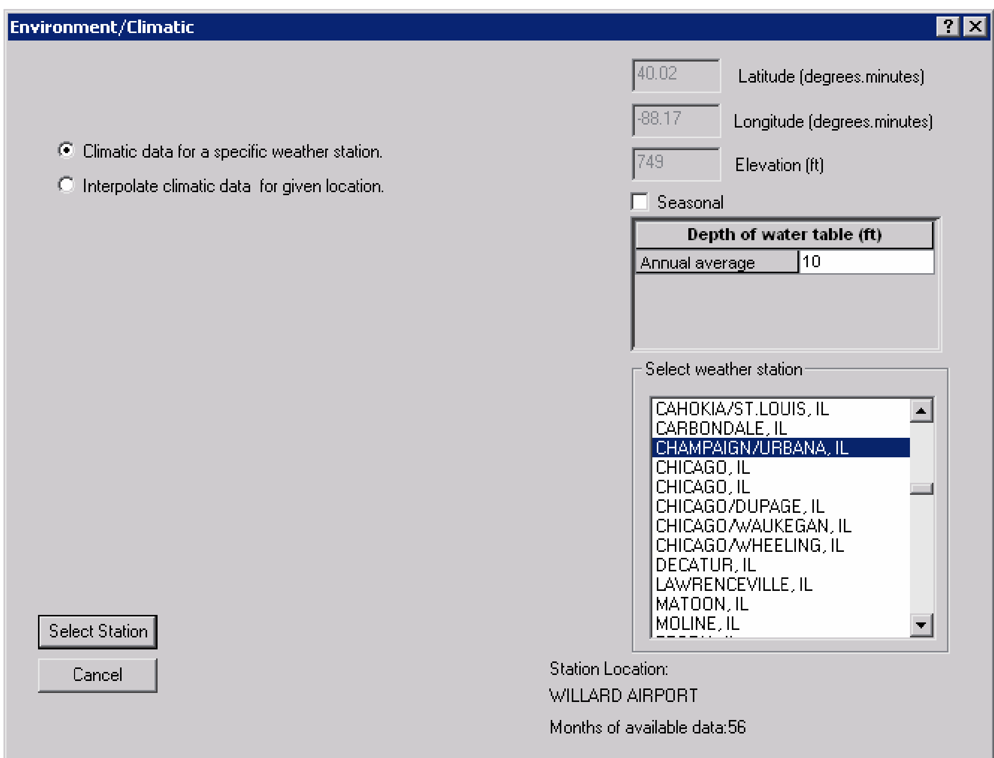


Figure D. 26. Generating climatic data file for the project location.

The program creates the climatic data file for the project. After the climatic data file is created, the program prompts the user to save it. Save the file in the project directory - *"C:\DG2002\Projects\JPCP\jpcp.icm"*.

Note that the program also automatically creates a file called *climate.tmp* in the project directory. This is the file that the program reads hourly climatic information from during the analysis stage. This file contains the sunrise time, sunset time and radiation for each day of the design life period. In addition, for each 24-hour period in each day of the design life, the temperature, rainfall, air speed, sunshine, and depth of ground water table are also listed in the climate file.

By this stage, the user has completed the climatic inputs required by the program. The color-coded icons will have a green color for the traffic and climate and red icons for structure, indicating that the traffic and climate inputs are complete and structural inputs are yet to be addressed.

D.2.5 Structural Inputs

The user at this stage needs to choose structural parameters and a layer combination that can be evaluated for its performance. As explained in the PART 3 of the Guide, the procedure is an iterative procedure and the user will have to develop a trial design and make several modifications to it, before a feasible and economic (or final) design is achieved.

Choose the following layers in the trial design for the given JPCP example:

1. 10.0-in JPCP layer
2. 4.0-in cement stabilized base layer
3. 6.0-in crushed stone subbase layer
4. Semi-infinite uncompacted (natural) subgrade layer

The JPCP slabs in the trial design will have a joint spacing of 15 feet and 1.25 inch diameter dowels across the transverse joints spaced at 12 inches. The joints will have a liquid sealant. The shoulders will contain no load transfer and will be provided with edge drains.

The structural inputs are of three categories, JP*CP Design Features, Drainage and Surface Properties*, and *Layer Properties*. These three categories of inputs have direct links from the program layout screen and no specific order is required to be followed to make these inputs.

D.2.5.1 *Design Features*

Click on the *Design Features* link on the main program layout screen and the program opens a screen to enable inputs for JPCP Design Features. The inputs to be made on this screen are shown in Figure D. 27.

The default slab thickness (which can be edited on the layers screen discussed in 2.5.3.1) appears on the screen on a non-edit mode. Enter a value of -10 for *permanent curl/warp effective temperature difference*. Enter *Joint spacing* of 15 feet and select the *Sealant type* as Liquid from the scroll down menu.

Next, click on the radio button corresponding to *Bonded* interface between the slab and the base layer. Because the chosen base layer is a cement stabilized base layer, choose an *Erodibility index* of 2 representing a *very erosion resistant base layer* and enter the *Loss of bond age* as 60 months.

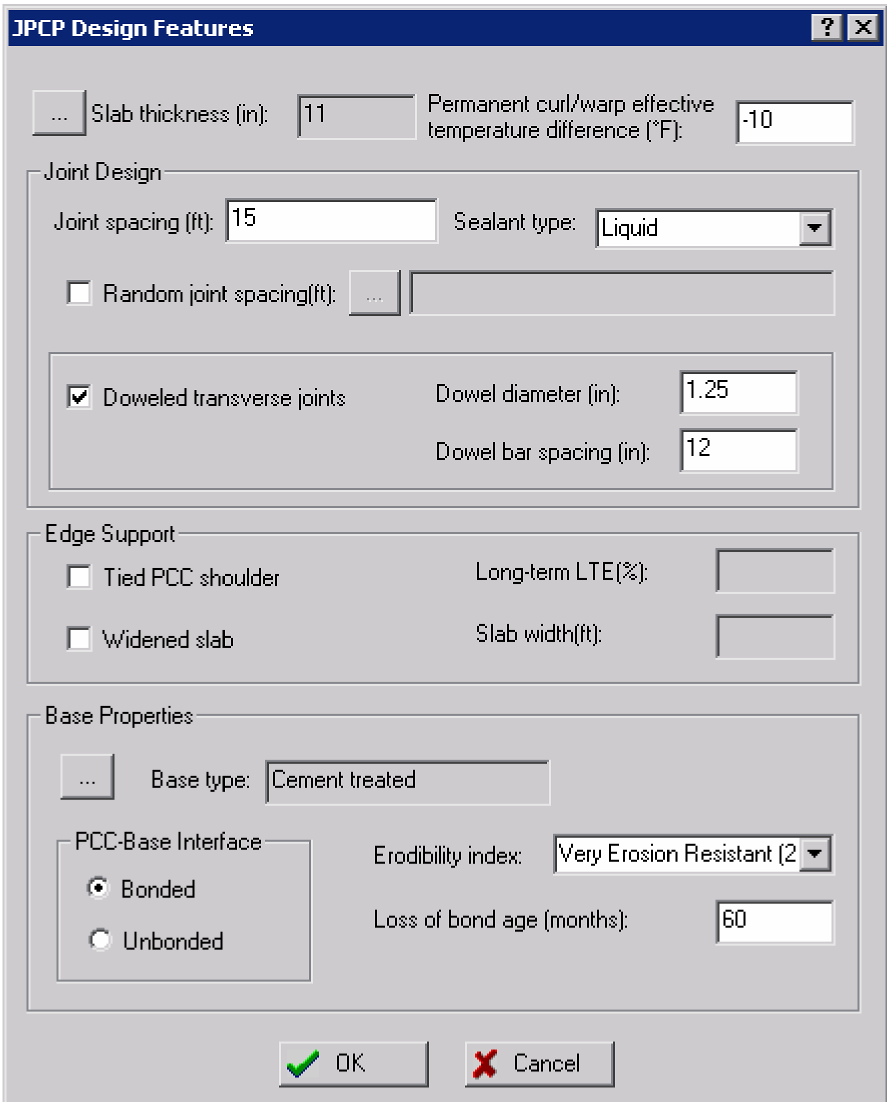


Figure D. 27. *JPCP Design Features* screen.

Note that on the *JPCP Design Features* screen shown in Figure D. 27, there are no inputs made with regard to *Edge Support* for this design example because of the absence of ties across the lane-shoulder joint. Finally, click *Ok* and return to the main program layout.

D.2.5.2 *Drainage and Surface Properties*

From the main program layout screen click on *Drainage and Surface Properties* to open the screen shown in Figure D. 28.

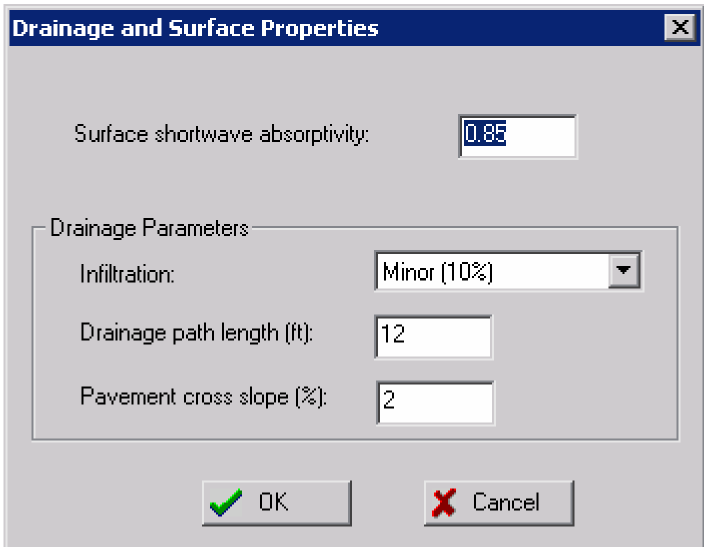


Figure D. 28. *Drainage and Surface Properties* screen.

Enter 0.85 for *surface shortwave absorptivity*. For shoulder with edge drains, the recommended infiltration is 10% corresponding to a *minor* level of infiltration. Enter 12 feet for the D*rainage path length* and 2 percent for P*avement cross slope*. Click *Ok* and return to the main program layout.

D.2.5.3 *Layers*

On the main program layout screen, click on *Layers* to add and edit pavement layers in the trial design. The program opens the Layers screen as shown in Figure D. 29. The three main functions this screen allows the user to perform are:

- Inserting a layer after a selected layer – by clicking the *Insert* button
- Deleting a selected layer – by clicking the *Delete* button
- Editing the layer properties of a selected layer – by clicking the *Edit* button

The first layer of the pavement, the PCC layer is shown on the screen in Figure D. 29. Next, the user has to add a layer after (underneath) the PCC layer. To add a layer after the PCC layer, select layer 1 by clicking on the row shown for Layer 1 and then insert a layer by clicking on the *Insert* button. The program now opens a screen shown in Figure D. 30a that allows the user to select the layer to be added as shown in Figure D. 30b.

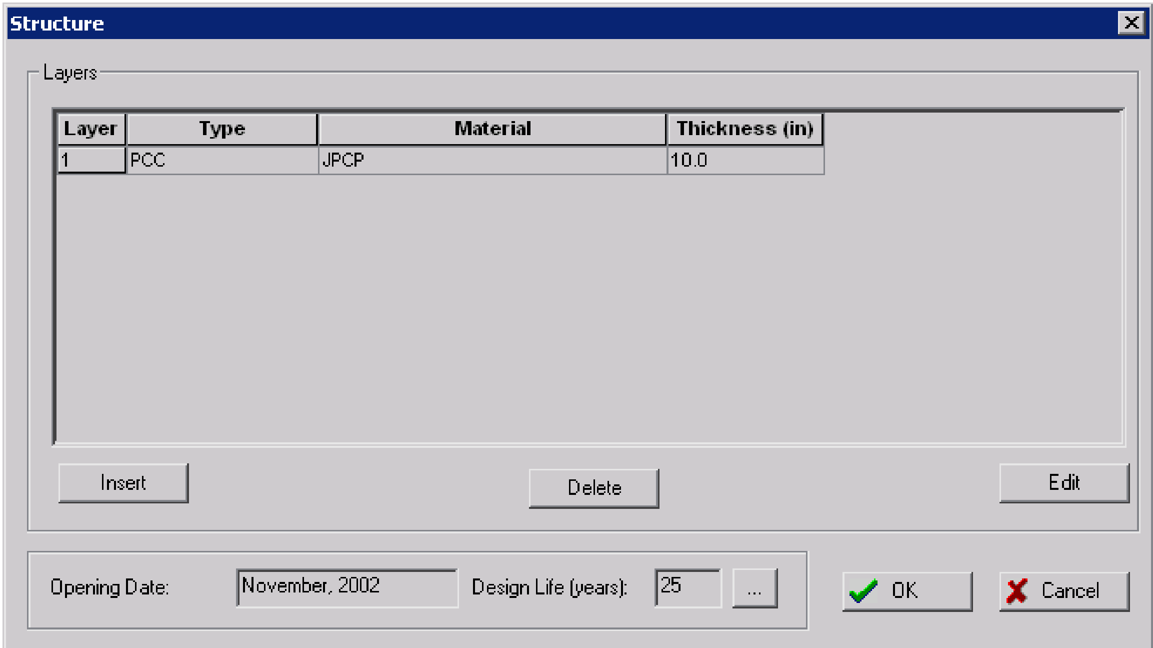
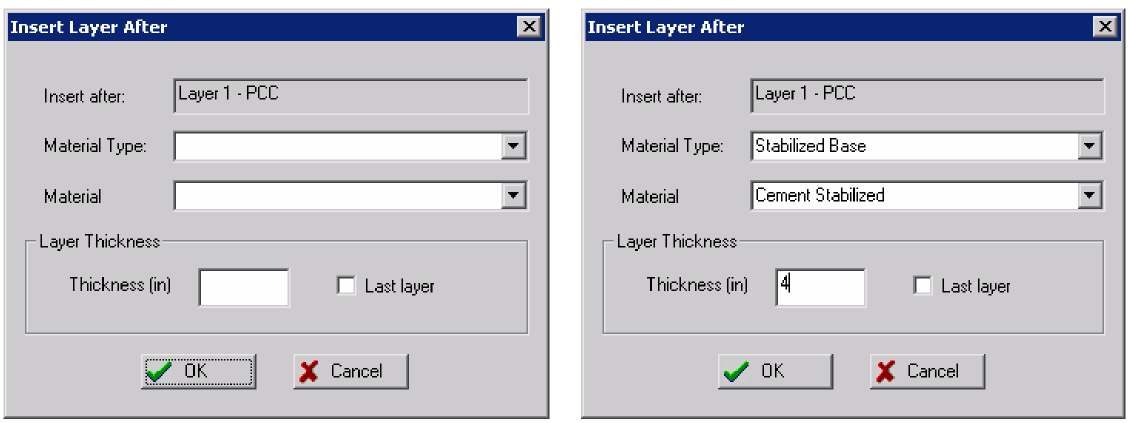


Figure D. 29. *Layers* screen.



a) Initial screen to insert layer b) Inputs to insert cement stabilized layer

Figure D. 30. Inserting cement stabilized layer after the PCC layer.

From the scroll down menu, select Stabilized Base for the M*aterial type* and Cement Stabilized for the *Material*. Enter a thickness value of 4 and click *Ok* to return to the *Layers* screen shown in Figure D. 31. This screen now shows the newly added cement stabilized layer.

Next, select layer 2 and click *Insert* to add a layer after the asphalt layer. Select Granular Base for the *Material type* and crushed stone for *Material* as shown in Figure D. 32. Enter a thickness of 6 inches Click *Ok* and return to the *Layers* screen shown in Figure D. 33.

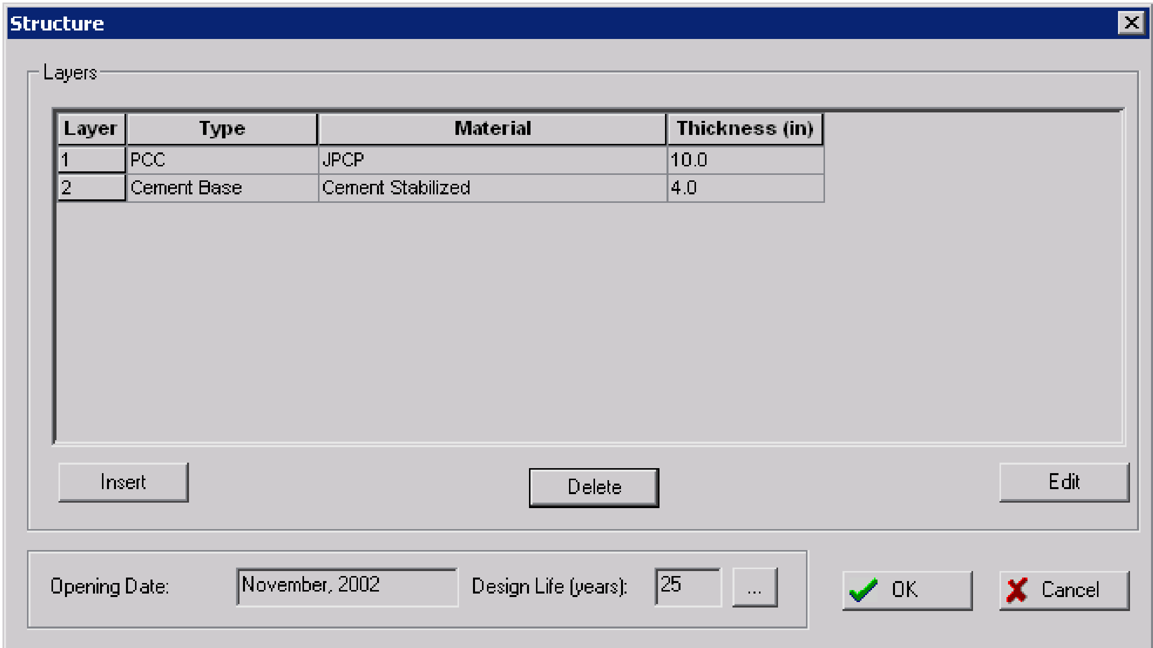


Figure D. 31. *Layers* screen after inserting the stabilized base layer.

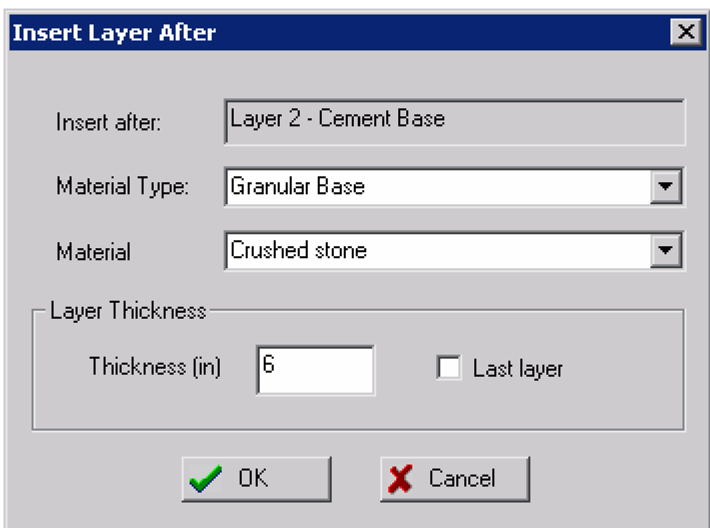


Figure D. 32. Inserting the granular base layer after the stabilized base layer.

Next, the user needs to insert the subgrade layer, which is the final layer of the pavement structure. It is recommended that in the absence of the granular base layer, the subgrade layer be entered as two layers to represent the semi-infinite subgrade and a layer above with compacted subgrade material. Please note that if the user fails to enter two distinct layers and chooses only one subgrade layer instead, the program will automatically prompt the user to add a second layer so that the drainage prediction model will function properly.

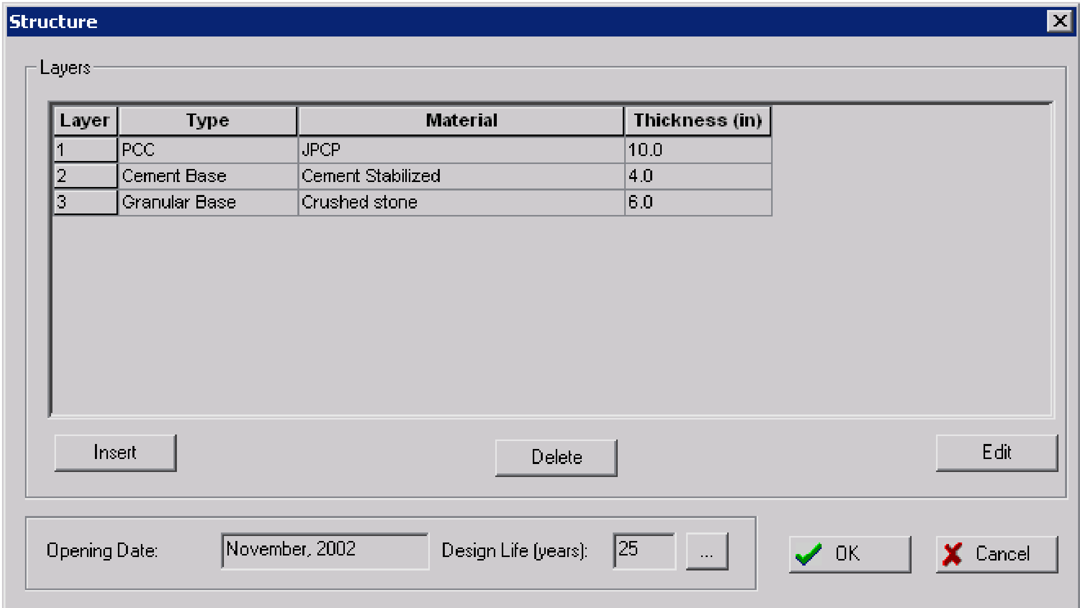


Figure D. 33. *Layers* screen after the addition of Layer 3 (granular base layer).

Repeat the same steps again and add the last layer. Select Layer 3 and click Insert. As shown in Figure D. 34, select Subgrade for *Material*, and based on AASHTO soil classification system, select A-6 for *Material type*. Select the *last layer* option instead of entering a thickness to this layer. Click *Ok* and return to the Layers screen that now has all four layers added to the structure as shown in Figure D. 35.

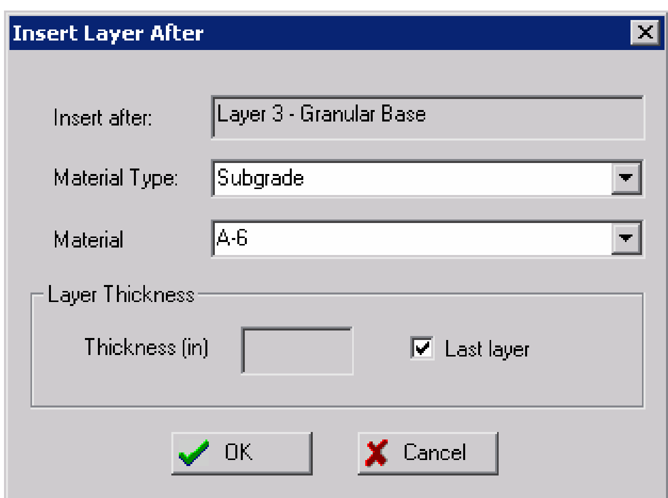


Figure D. 34. Inserting the uncompacted subgrade layer after the compacted subgrade.

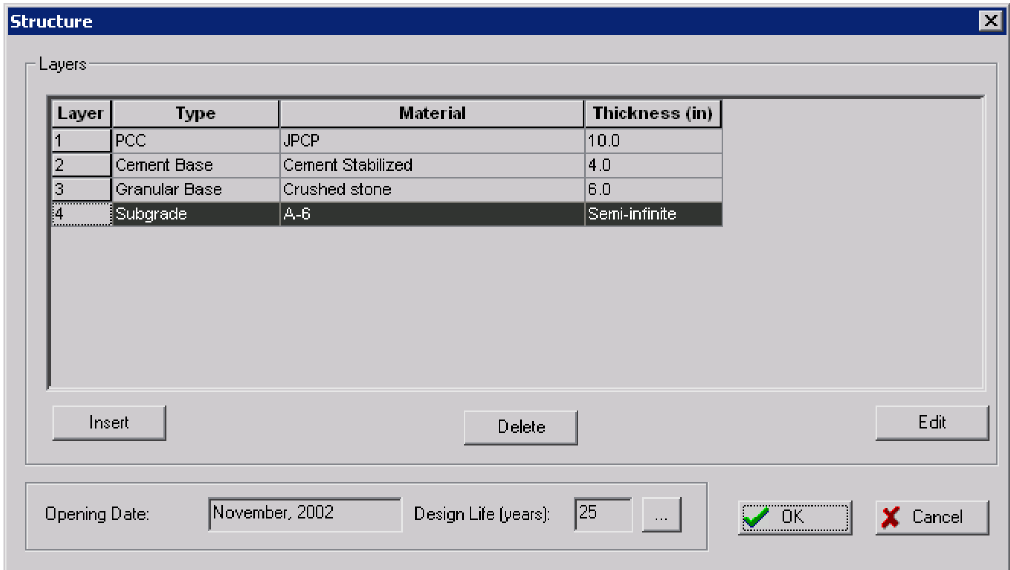


Figure D. 35. *Layers* screen after the addition of all layers.

The individual screens for the input of layer material properties can be accessed either from the *Layers* screen shown in Figure D. 35, or directly from the program layout screen. To access the material properties screen from the *Layers* screen, select the desired pavement layer and click on *Edit*. To return to the program layout screen, click *Ok* on the *Layers* screen. The program layout screen now, as shown in Figure D. 36.

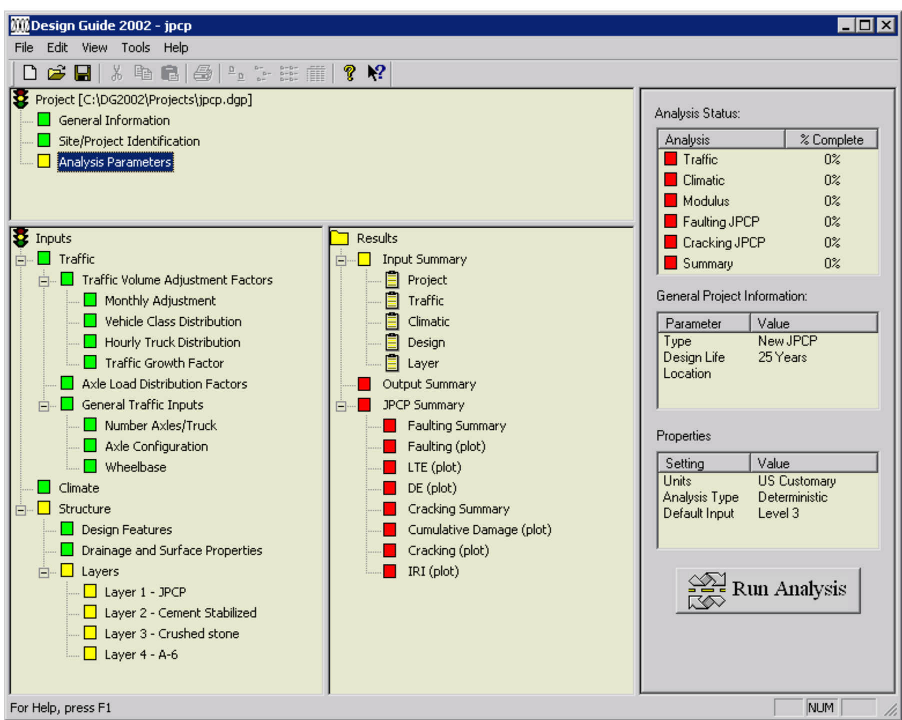


Figure D. 36. Program layout screen after adding all layers.

D.2.5.3.1 *Layer 1 – JPCP*

Click on *Layer 1 – JPCP* to edit PCC layer material properties. This opens a screen with three property pages for *Thermal*, *Mix*, and *Strength* properties. On the Thermal properties screen, as shown in Figure D. 37, enter the following inputs:

Layer thickness = 10 inches
Unit weight = 145 pcf
Poisson's ratio = 0.20
Coefficient of thermal expansion = 6.3 in/in/^{o}F
Thermal conductivity = 1.25 BTU/hr-ft-^{o}F
Heat capacity = 0.28 BTU/lb-^{o}F

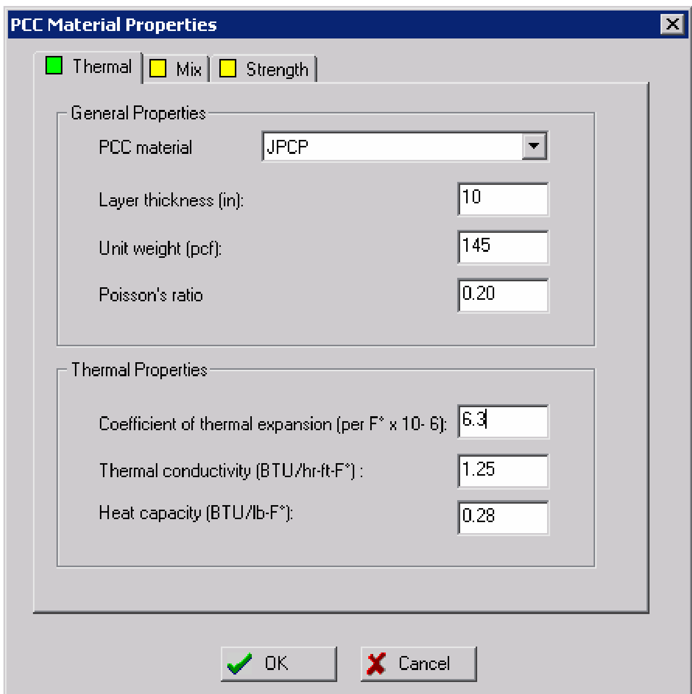


Figure D. 37. *PCC Material Properties – Thermal Properties* screen.

Next, click on the *Mix* tab and move to the property page requiring inputs specific to the mix. As shown in Figure D. 38, the following inputs are made:

Cement Type : Type 1 (from draw down menu)
Cement content: 565 lb/yd^3
Water cement ratio: 0.402
Aggregate type: Dolomite (from the draw down menu)
Ultimate shrinkage: Leave box unchecked for the program to internally calculate value.
Reversible shrinkage: 50%
Time to develop 50% of ultimate shrinkage: 35 days
Curing method: Curing compound (from draw down menu)

Next click on the *Strength* tab and move to the property page requiring inputs for concrete strength properties. This screen is shown in Figure D. 39. Click the radio button corresponding to level 1 inputs. The screen provides an array format to enter the strength and modulus values at different ages. Enter values for concrete modulus and modulus of rupture as shown in Figure D. 39.

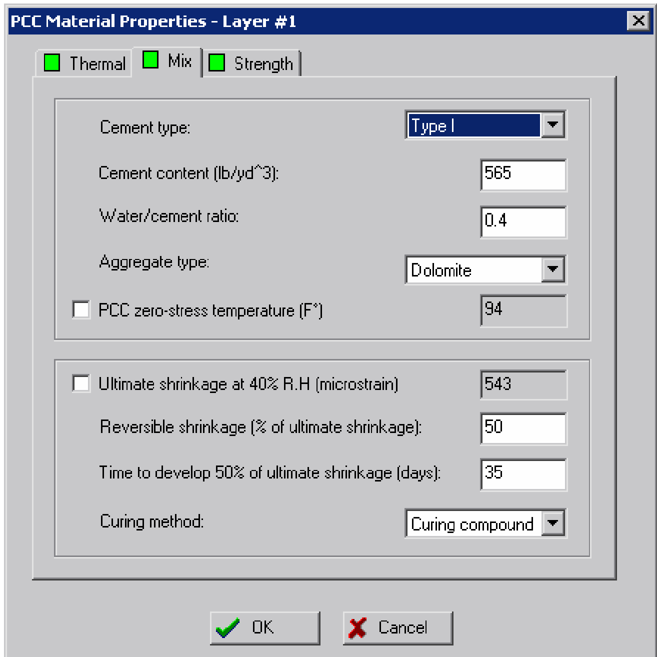


Figure D. 38. *PCC Material Properties – Mix Properties* screen.

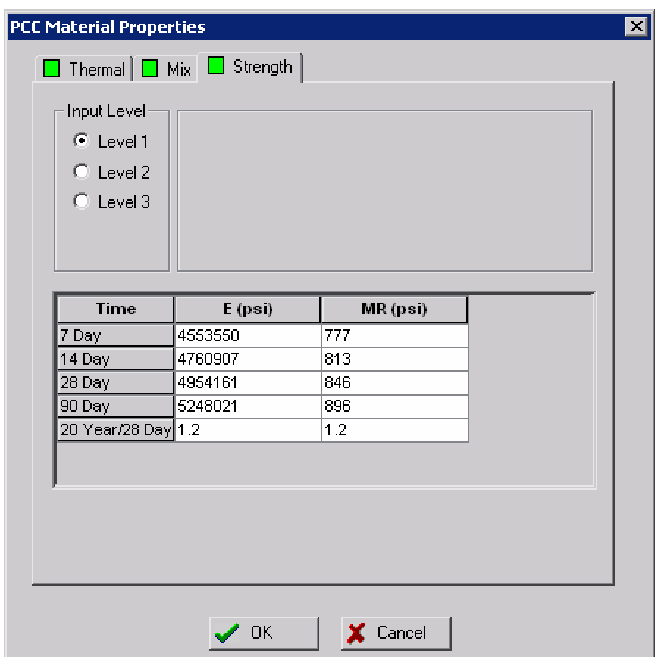


Figure D. 39. *PCC Material Properties –Strength Properties* screen (level 1).

Note that the tensile strength values are not required inputs for a JPCP design, and compressive strength values are not required for level 1 input. Click *Ok* and return to the program layout screen. Note that Layer 1 button is now green.

D.2.5.3.2 *Layer 2 – Cement Stabilized*

Click on Layer 2 on the program layout screen. The chosen material type and thickness appear on the screen (Note that this information can be modified on this screen). Enter the following inputs as shown in Figure D. 40,

Unit weight: 150 pcf
Poisson's ratio: 0.20
Resilient modulus: 1,789,845 psi
Thermal conductivity: 1.25
Heat capacity: 0.28

Click *Ok* and return to the main program layout screen. Note that the icon adjacent to *Layer 2 – Cement stabilized* layer is now green

.

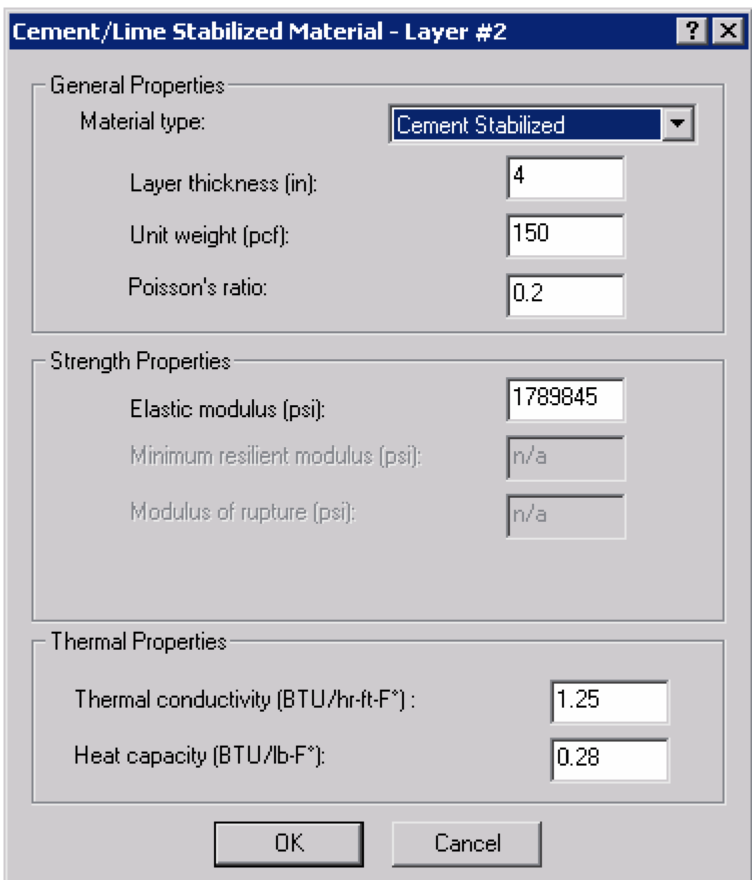


Figure D. 40. *Cement Stabilized Material* screen.

D.2.5.3.3 Layer 3 – Crushed stone

Click *on Layer 3 – Crushed stone* ML on the program layout screen to enter inputs for the crushed stone base layer. The screen that enables the user to make inputs for an unbound layer opens as shown in Figure D. 41. Note that the choice made for the unbound material type and the layer thickness appear on the screen. (This screen also allows the user to make changes to these choices if necessary).

Choose the radio button corresponding to *level 3 inputs*, which requires only the input for modulus for material property. Enter the following input values:

> Poisson's ratio: 0.35
> Coefficient of lateral pressure: 0.50
> Modulus (psi): 40,000

For *Analysis Type*, click on the radio button adjacent to *ICM Inputs* to indicate that the user will make ICM inputs to the program

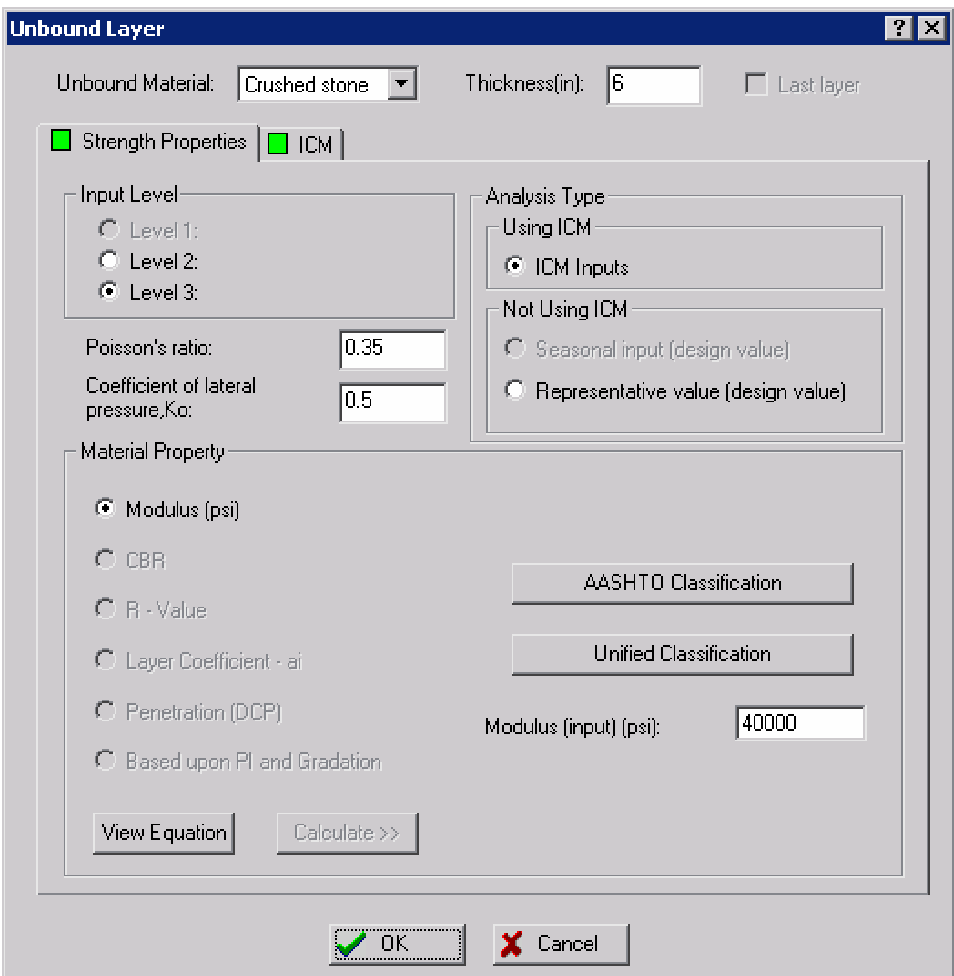


Figure D. 41. *Unbound Layer* screen for crushed stone base layer – *Strength Properties.*

Next, click on the *ICM* tab to make ICM inputs. The inputs made on this screen, shown in Figure D. 42, are as follows:

Plasticity Index, PI: 1 (given)
Passing #200 sieve (%): 10 (default)
Passing #4 sieve (%): 80 (default)
D60 (mm): 2 (given)

Select the radio button corresponding to a compacted unbound layer because the base material is compacted before the placing the treated base layer. Click on *Update* and view the ICM calculated parameters. Next, click *Ok* and return to the main program layout screen.

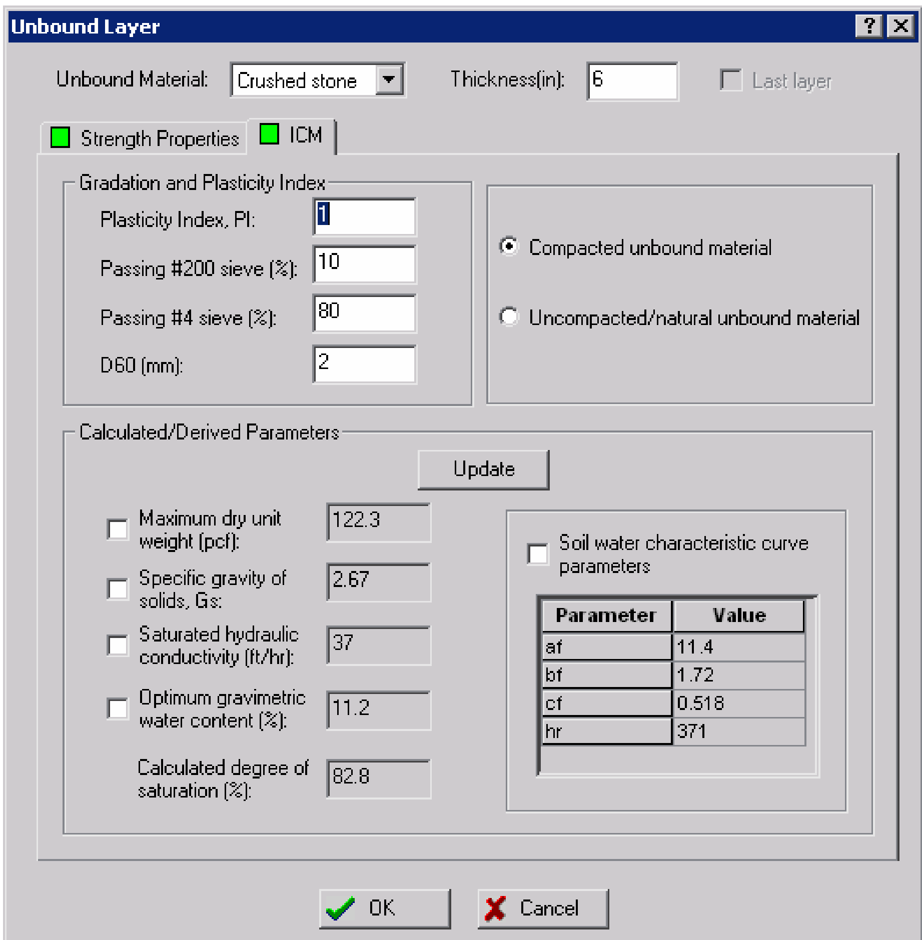


Figure D. 42. *Unbound Layer* screen for crushed stone base layer – *ICM Properties.*

<u>D.2.5.3.4 *Layer 4 – A-6*</u>

The fourth layer in this trial design is the natural subgrade classified as A-6 in this geographic area as per the AASHTO classification system. Click on *Layer 4 – A-6* on the program layout screen. The input screen for unbound materials is opened for material strength and ICM property inputs. Choose the radio button corresponding to level 3 inputs, which requires only the input for modulus for material property. Enter the following input values on the *Strength Properties* page as shown in Figure D. 43:

Poisson's ratio: 0.35
Coefficient of lateral pressure: 0.50
Modulus (psi): 18,000

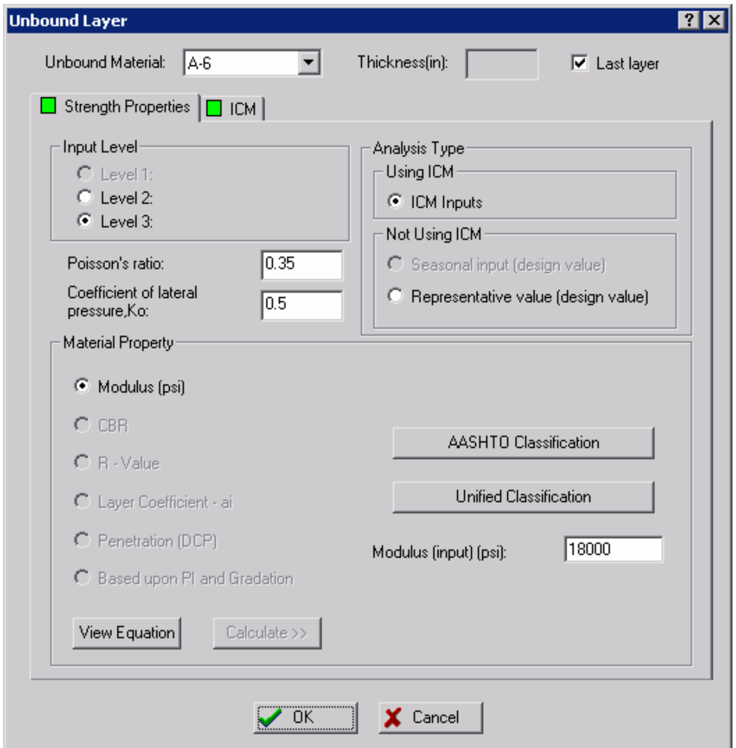


Figure D. 43. *Subgrade (Unbound) layer* screen – *Strength Properties* page.

For *Analysis Type*, click on the radio button adjacent to *ICM Inputs* to indicate that the user will make ICM inputs to the program. Next click on the ICM tab and on the ICM property page, enter the following inputs as shown in Figure D. 44:

Plasticity Index, PI: 25
Passing #200 sieve (%): 80
Passing #4 sieve (%): 95
D60 (mm): 0.01

Next, click on the radio button corresponding to *Uncompacted /natural unbound material* and then on *Update* to view the ICM calculated parameters. Next, click *Ok* and return to the program layout screen shown in Figure D. 45. Note that in Figure D. 45, the icons adjacent to all inputs—*Traffic*, *Climate, and Structure*—are green indicating that all these inputs are complete.

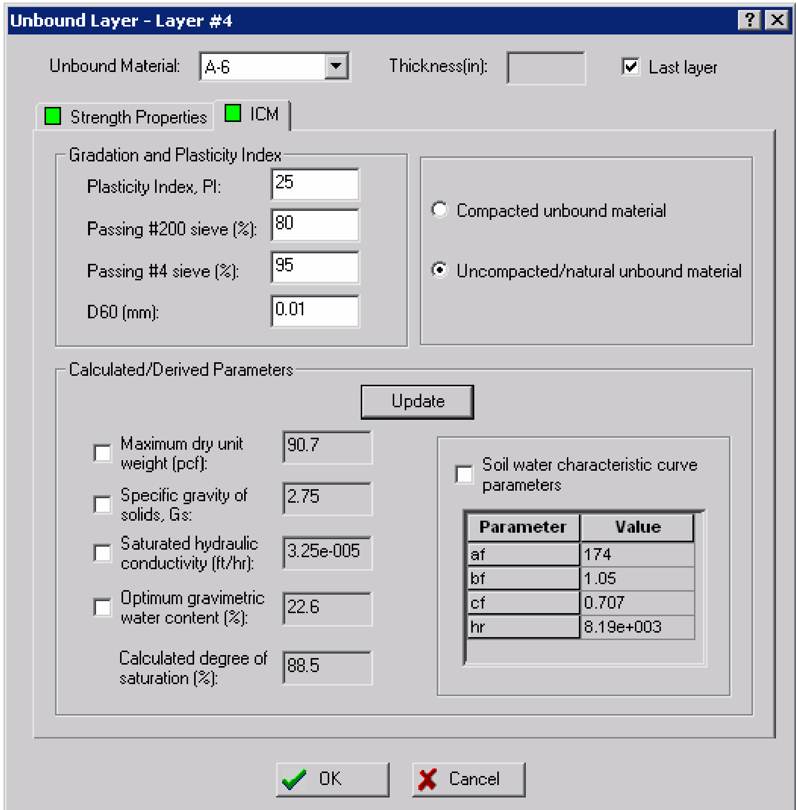


Figure D. 44. *Unbound layer* screen for natural subgrade layer.

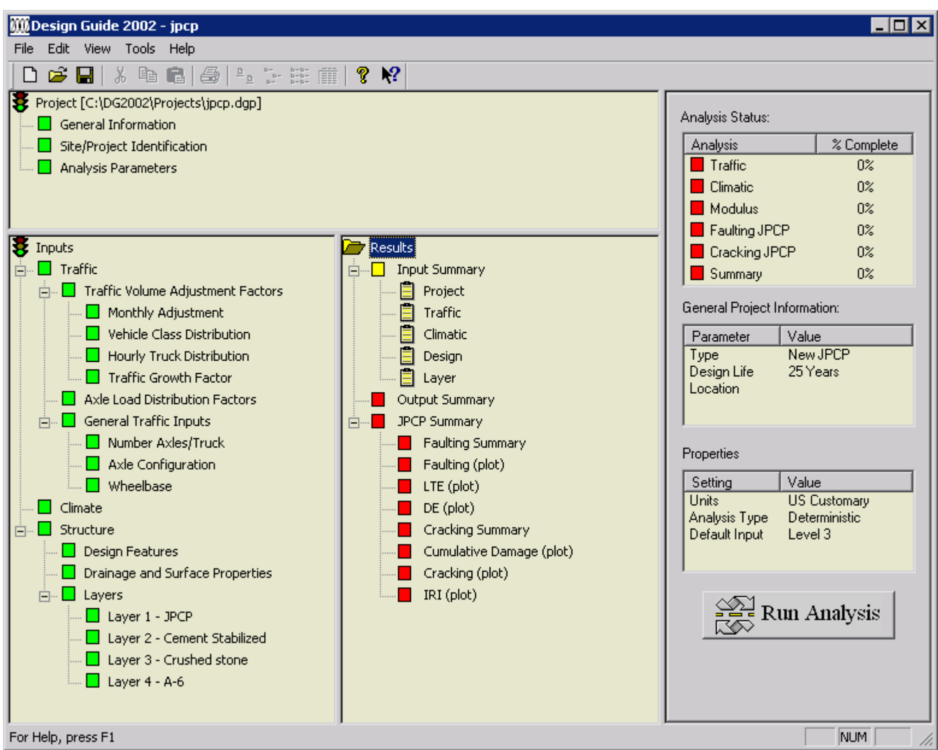


Figure D. 45. Program layout screen after completing all inputs.

D.2.6 Run Analysis

After all design inputs are provided, the Design Guide software has to begin the analysis process to predict the performance of the trial design over the design life of the pavement. Click on *Run Analysis*. The program runs the Traffic, Climate, Modulus, faulting JPCP, Cracking JPCP modules and reports the analysis status on the upper right hand corner of the screen.

At the end of the analysis, the program creates a summary file and other output files in the project directory, C:\DG2002\Projects\JPCP. The summary file is in a MS Excel format and is named "*JPCP.xls*." The summary file contains an input summary sheet, distress, faulting, and cracking summary sheets in a table format, and the predicted faulting, LTE, differential energy, cumulative damage, cracking, and IRI in a graphical format.

The distress summary sheet in the output file provides an overall summary of the JPCP design for the project including critical material properties, traffic, and distress data. Detailed data for each distress type is provided on separate sheets. The distress summary sheet indicates that this pavement carried 15.5 million heavy trucks over the design period and this provides an overall idea of the traffic loading on the pavement.

For the given trial design, the transverse cracking and faulting over the design life as predicted by Design Guide software at the selected reliability level are shown in Figure D. 46 and in Figure D. 47 respectively. The predicted IRI is shown in Figure D. 48. From these three figures it is clear that the trial design satisfies the smoothness and transverse criteria but fails to satisfy the faulting criteria specified.

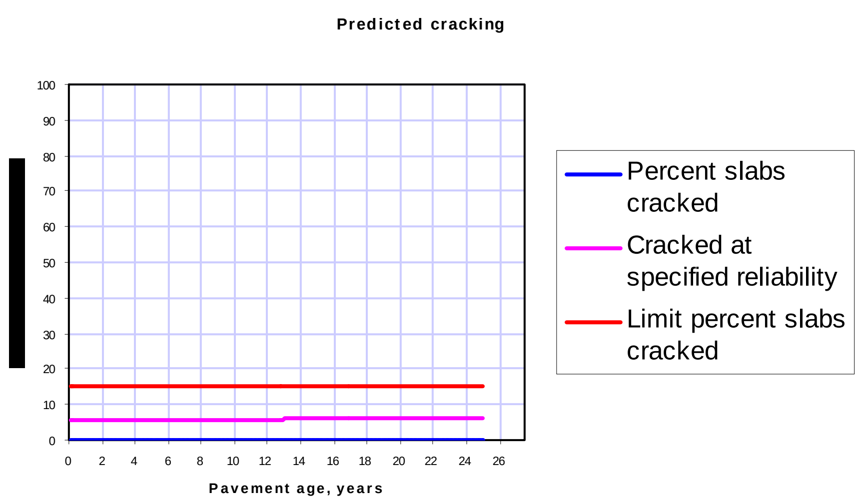


Figure D. 46. Predicted transverse cracking at 95 percent reliability for the trial design.

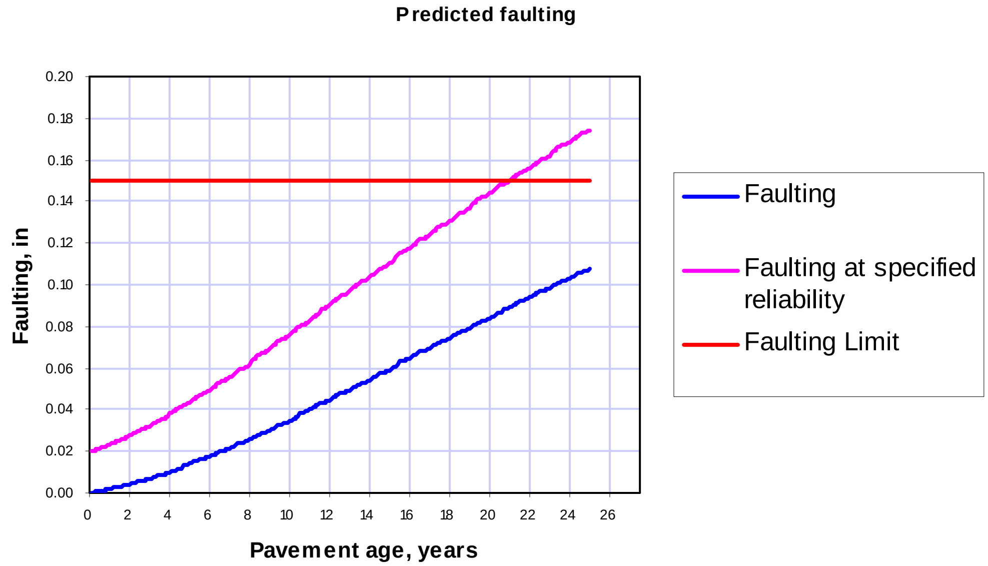


Figure D. 47. Predicted faulting at 90 percent reliability for the trial design.

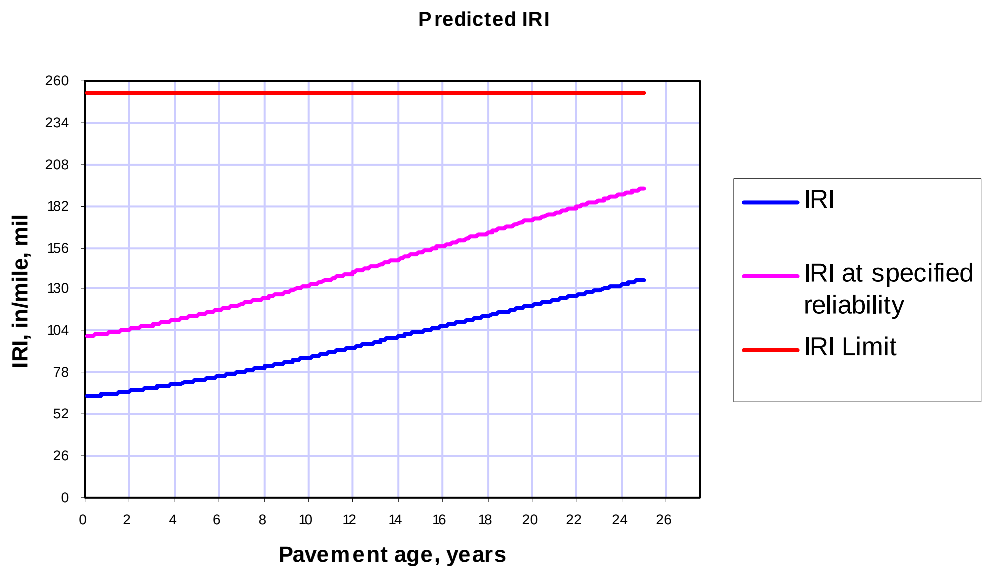


Figure D. 48. Predicted IRI at 95 percent reliability for the trial design.

D.2.7 Modify Trial Design

The user now has to modify the trial design so that the faulting criterion is also met. The user has to run several different cases to select the optimum from the feasible design options developed. Possible modifications to this trial design are:

- Increase the slab thickness (not best or economical alternative)

- Increase the diameter of the dowel bar across the transverse joint
- Increase dowel bar size and decease thickness
- Increase thickness and decrease dowel diameter (uneconomical alternative)

The predicted faulting of the pavement at 90% reliability level for various thickness and steel content parameters are summarized, Figure D. 49, and Figure D. 50. The predicted transverse cracking and IRI at 95% reliability at the end of design life for the slab thickness and dowel sizes considered are tabulated below:

Slab thickness (inch)	Dowel diameter (inch)	Faulting at 90% reliability (inch)	Cracking at 95% reliability, (% slabs cracked)	IRI at 95% reliability (in/mile)
10	1	0.30	6.1	263.1
10	1.25	0.17	6.1	192.8
10	1.375	0.14	6.1	173.3
10	1.5	0.12	6.1	164.6
11	1	0.24	5.6	230.1
11	1.25	0.16	5.6	183.2
11	1.375	0.12	5.6	162.7
11	1.5	0.10	5.6	154.6

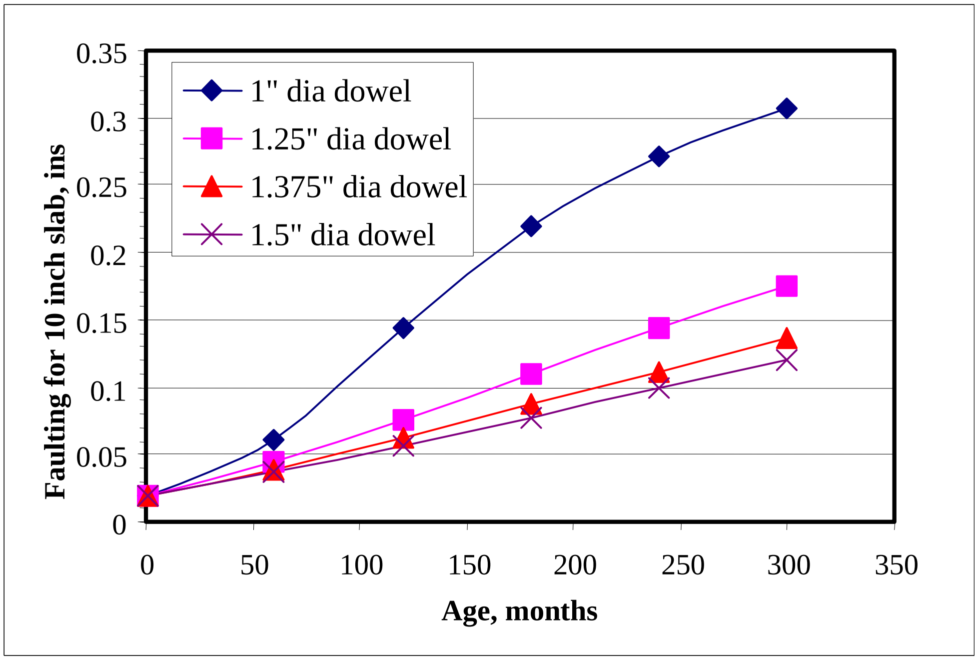


Figure D. 49. Predicted faulting at 90 % reliability for 10-inch thick slab.

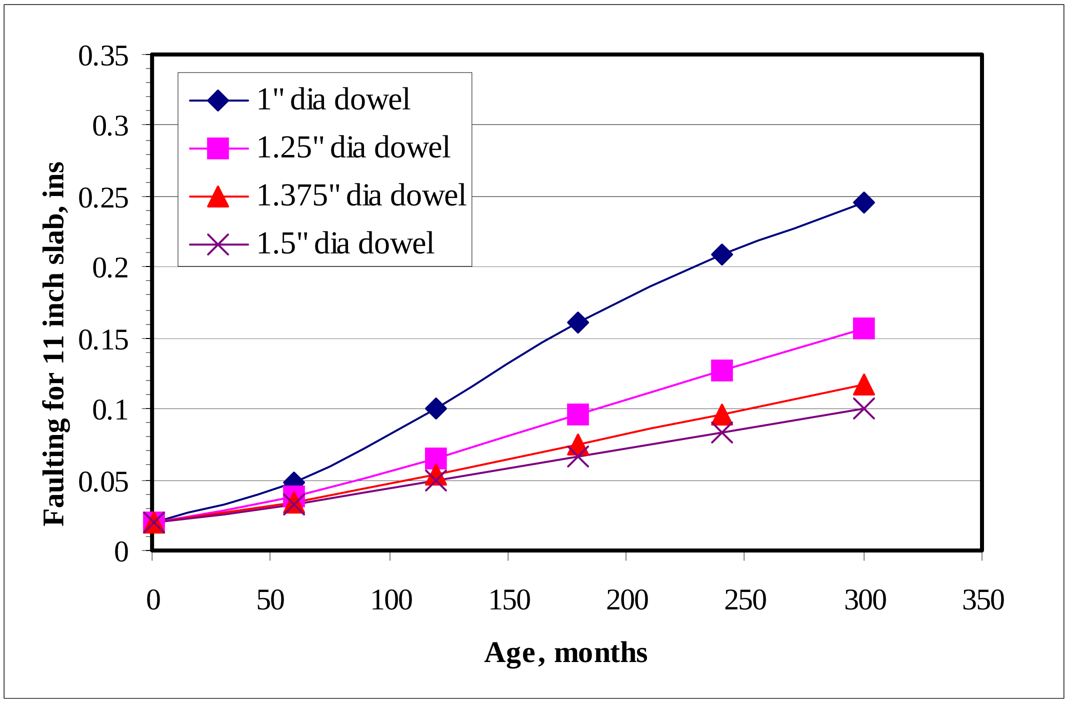


Figure D. 50. Predicted faulting at 90 % reliability for 11-inch thick slab.

From the results presented in Figure D. 49 and Figure D. 50, the feasible design options are clearly the 10 and 11-inch pavement sections with 1.375 and 1.5-inch diameter dowels.

Note that several input parameters used in the design can affect the predicted performance. Although the above design example for JPCP suggests altering the thickness and/or dowel diameter, several other parameters that can be modified to meet the desired performance requirements. Examples of such input values are strength of the concrete mix design, the choice of the base layer, thickness of the base layer, shoulder type, etc. Refer Appendix JJ and KK of the Guide for further illustration of the effects of design parameters in the prediction of faulting and cracking in JPCP.

D.3 CRCP DESIGN EXAMPLE

Design Life

The continuously reinforced concrete pavement has a 30-year design life and will be constructed in the month of August 2002 to be opened to traffic in September 2002.

Construction Requirements

Assuming a good quality of construction, the pavement shall have an initial IRI between 50 and 75 in/mile (assume 63 in/mile for design purposes).

Analysis Parameters

It is expected that at the end of the 30-year design life, the pavement will have no more than 10 punchouts per mile at 95% reliability and an IRI of less than 252.

Location

The pavement is in the state of Illinois and in the east central region of the state. It is located at 39.90 deg latitude, –88.30 deg longitude and at an elevation of 700 feet. The depth of the water table is 10 feet at this site.

The 5-mile stretch of pavement to be designed is in the westbound lane called CRCP1 between mileposts 00 + 00 to 05+00.

Traffic

The two-way average annual daily truck traffic (AADTT) on this highway is estimated to be 2250 trucks during the first year of its service. There will be two lanes in the design direction with 90% of the trucks in the design lane. Truck traffic is equally distributed in both directions (i.e. 50% of the trucks drive in the design direction). The operational speed is 60 mph.

This pavement is being designed for heavy traffic in a principal arterial/Interstate category highway and therefore the traffic consists of a high percentage of single trailer trucks. Information collected at this specific site shows that the percentage of AADTT in each vehicle class is as follows:

Vehicle Class	Percent AADTT in Class
Class 4	1.8
Class 5	6.7
Class 6	2.5
Class 7	0.2
Class 8	4.8
Class 9	80.1
Class 10	0.9
Class 11	2.5
Class 12	0.4
Class 13	0.1

For each class of vehicle, the traffic pattern on monthly and daily bases remains the same through out the year. However, the traffic varies over a 24-hour period and is same as the national default based on LTPP data (provided in the Design Guide and the software).

After the base year, over the design life of the pavement, the traffic increases by 4.0% of the preceding year's traffic (compounded annually).

The axle load distribution is identical to the national defaults (derived from LTPP) provided with the Design Guide software for each vehicle class, axle type, load category, and months of the year.

Assume that the mean of the outer wheel edge is located 18 inches from the edge of the pavement. The truck lateral wander has a standard deviation of 10 inches. The pavement has a standard design lane width is 12 feet. The number of single, tandem, tridem and quad axles for each vehicle class is also same as the national defaults derived from LTPP data (provided in the Design Guide and the software).

The axle configuration is as follows:

Average axle width (edge-to-edge outside dimensions, ft): 8.5
Dual tire spacing (in): 12

The single and dual tire pressures are 120 psi. The design lane is 12 feet wide. The average axle spacing for tandem, tridem and quad axles are as follows:

Axle type	**Axle spacing (in)**
Tandem	51.6
Tridem	49.2
Quad	49.2

Drainage and Surface Properties

The geometric design of the highway calls for a cross slope of 2 percent. The drainage path will have a length of 12 feet from the centerline to the edge drain adjacent to the lane-shoulder joint, and the infiltration will depend on the chosen shoulder type. Assume a surface shortwave absorptivity of 0.85.

CRCP Design Features

It is anticipated that the temperature and curing conditions will induce a permanent curl/warp equivalent to –10 deg F in this section if a curing compound is used during the curing process.

Concrete Mix Properties

Concrete mix design to be used in this project has level 1-strength tests for the concrete, modulus of elasticity, modulus of rupture, and tensile strength. Tests have been performed at concrete ages of 7, 14, 28, 90 days respectively. Because a long-term strength test could not be performed, estimates of 20-year to 28-day strength and modulus ratios were provided as recommended in the Guide. The results from the laboratory tests are summarized as:

Time, days	E_{PCC}, psi	MR, psi	S.T., psi
7	4553550	777	579
14	4760907	813	605
28	4954161	846	630
90	5248021	896	668
20 yr to 28 day strength ratio	1.2	1.2	1.2

The coefficient of thermal expansion of the mix was found to be 6.3 in/in/deg F. Assume a thermal conductivity of 1.25 BTU/hr-ft-^{o}F and a specific heat of 0.28 BTU/lb-^{o}F. The unit weight and Poisson's ratio of the mix were 145 pcf and 0.20 respectively. The concrete mix design comprised of Type 1 cement, with a cement content of 565 lb/cubic yard and a water cement ratio of 0.402. The aggregate type used for this mix design is dolomite. Shrinkage characteristics of the mix indicate that its reversible shrinkage is 50% of its ultimate shrinkage value and it takes 35 days to develop 50% of its ultimate shrinkage.

Subgrade

The subgrade in this location is classified as "fine-grained soils, sandy lean clay" and has a M_r value of 20,000 psi estimated at optimum moisture conditions. The plasticity index of the soil is 15. Results from sieve analysis of this subgrade soil indicated that 68.5 % of the material passes the #200 sieve, and 97% the #4 sieves. The D_{60} of this material is 0.0265mm:

Trial Design

The Design Guide procedure is an iterative procedure that requires the user to develop a trial design to begin the design process. The trial design is analyzed over the design period specified by the designer. The trial design is then evaluated based on the design criteria and then suitably modified until a final design is achieved. The design process is integrated into the Design Guide software program. The design process requires the following steps:

D.3.1 Create a New project

D.3.1.1 Create a new design project in the Design Guide program

Open the Design Guide program from the *Programs* menu of the operating system (windows 98, 2000, XP, NT). Next open a new file and assign a name to the project, "*CRCP Example*" as shown in Figure D.51. Next, select the folder to store the design files as "*C:\DG2002\Projects*". Select US Customary units as the measurement system by clicking the radio button next to it. Next, click "*OK*" and the program opens the main layout screen of the design project as shown in Figure D.52.

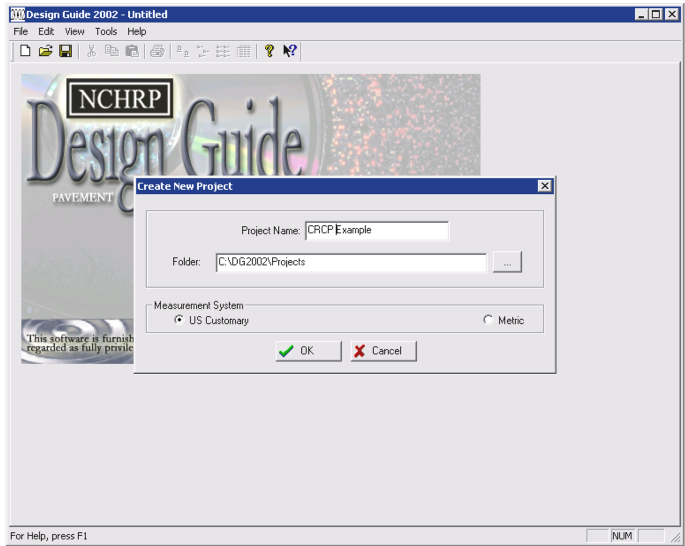


Figure D.51. Create a new project file from the main program.

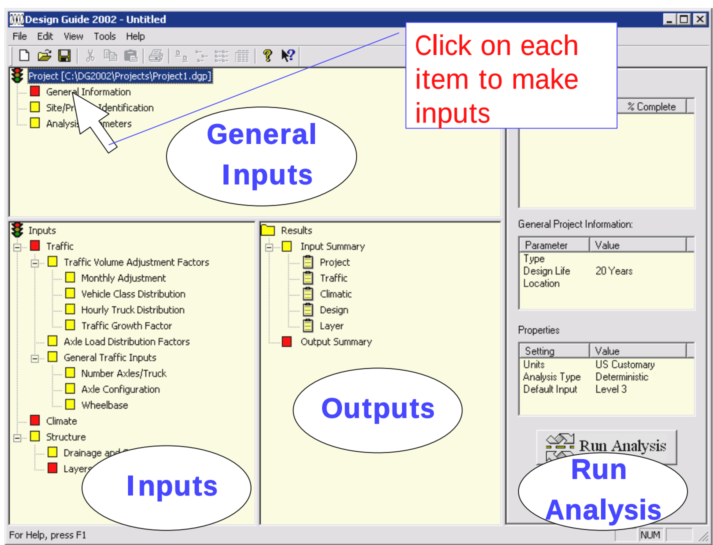


Figure D.52. Main program layout.

D.3.2 General Inputs

<u>D.3.2.1 *General Information*</u>

On the main project screen click on the *General Information* input to open the *General Information* screen. Inputs on General Information Screen as shown in Figure D.53:

Design Life: 30 years
Pavement Construction Month: August 2002
Traffic Open Month: September 2002
Type of Design: New Pavement – Continuously Reinforced Concrete Pavement (CRCP)

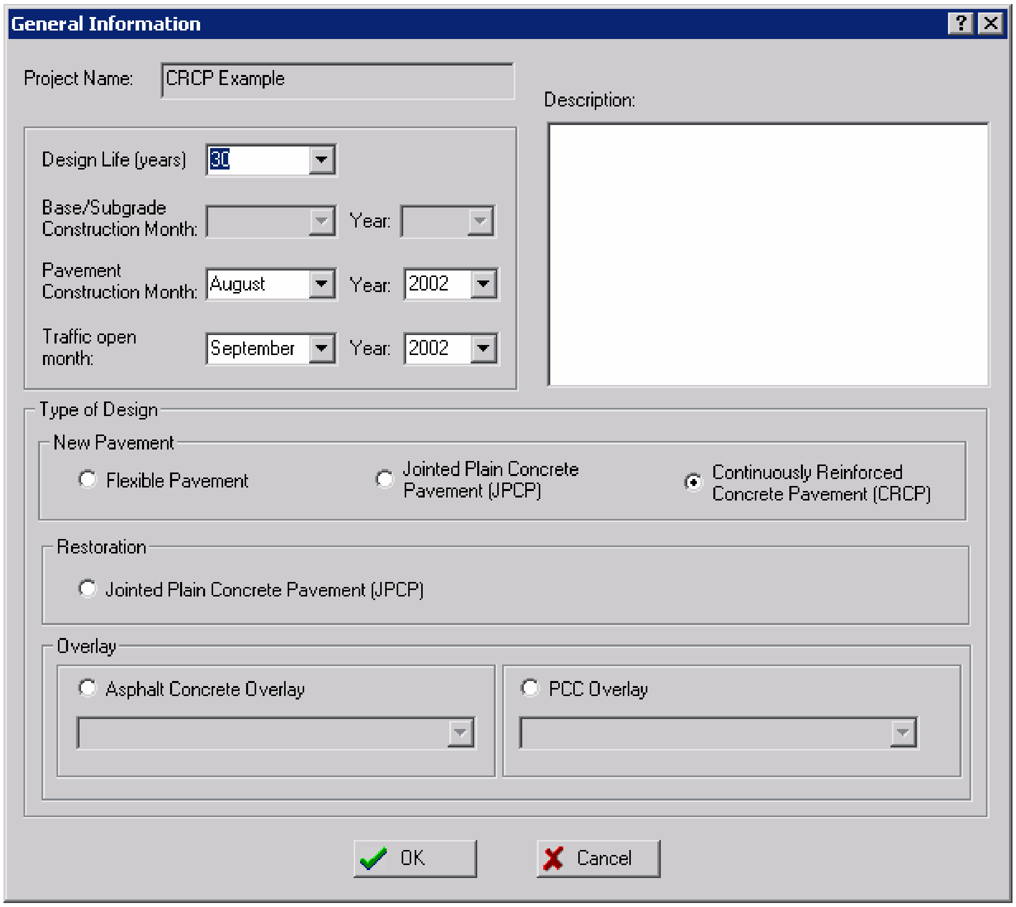


Figure D.53. *General Information* screen.

Click *OK* and return to the program layout screen

D.3.2.2 *Site/Project Identification*

Click on *Site/Project Identification* to open the *Site/Project Identification* screen. Inputs made on this screen are purely for providing identification to the project. Inputs to be made for this design, as Figure D.54

Location: Illinois
Project ID: CRCP Design Example
Section ID: CRCP1
Functional Class (from pull-down menu): Principal Arterials – Interstate and Defense
Date: Date performing the design
Station/milepost format: 00+00
Station/milepost begin: 00 + 00
Station/milepost end: 05 + 00
Traffic Direction: Westbound

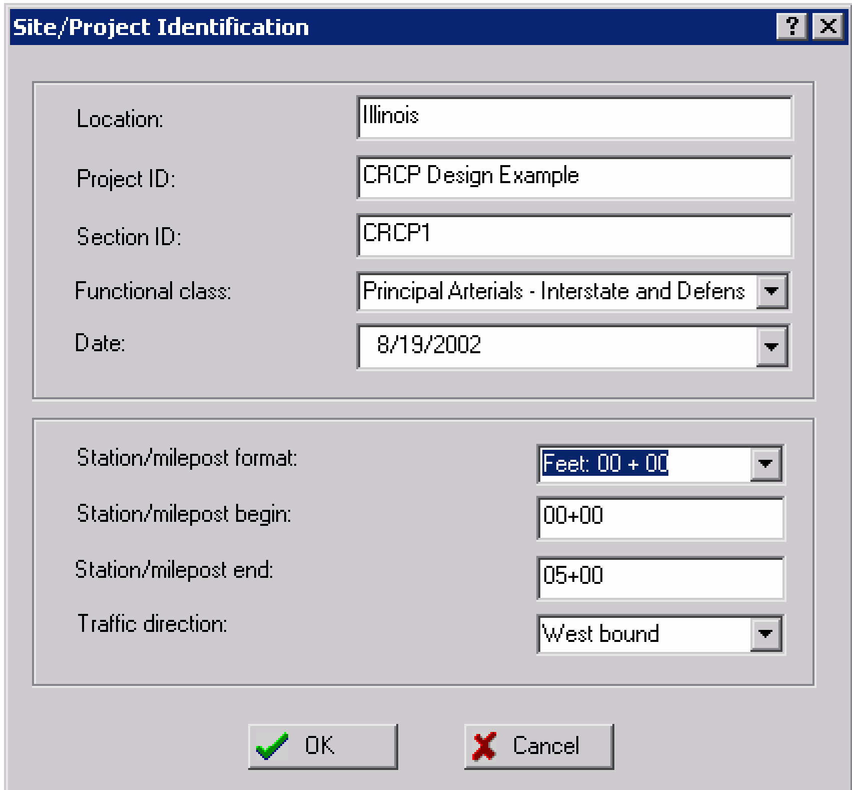


Figure D.54. *Site/Project Identification* screen.

Click *OK* and return to the main layout program.

D.3.2.3 *Analysis Parameters*

This screen allows the user to make inputs with regard to design criteria chosen by the agency. For this specific example, the inputs to be made on the *Analysis Parameters* screen, as show in Figure D.55 are as follows:

Initial IRI (in/mile): 63
Analysis Type: Probabilistic
Performance Criteria
- Terminal IRI (in/mile): 252
- Reliability (for IRI criteria): 95
- CRCP Punchouts per mile: 10
- Reliability (for punchouts): 95

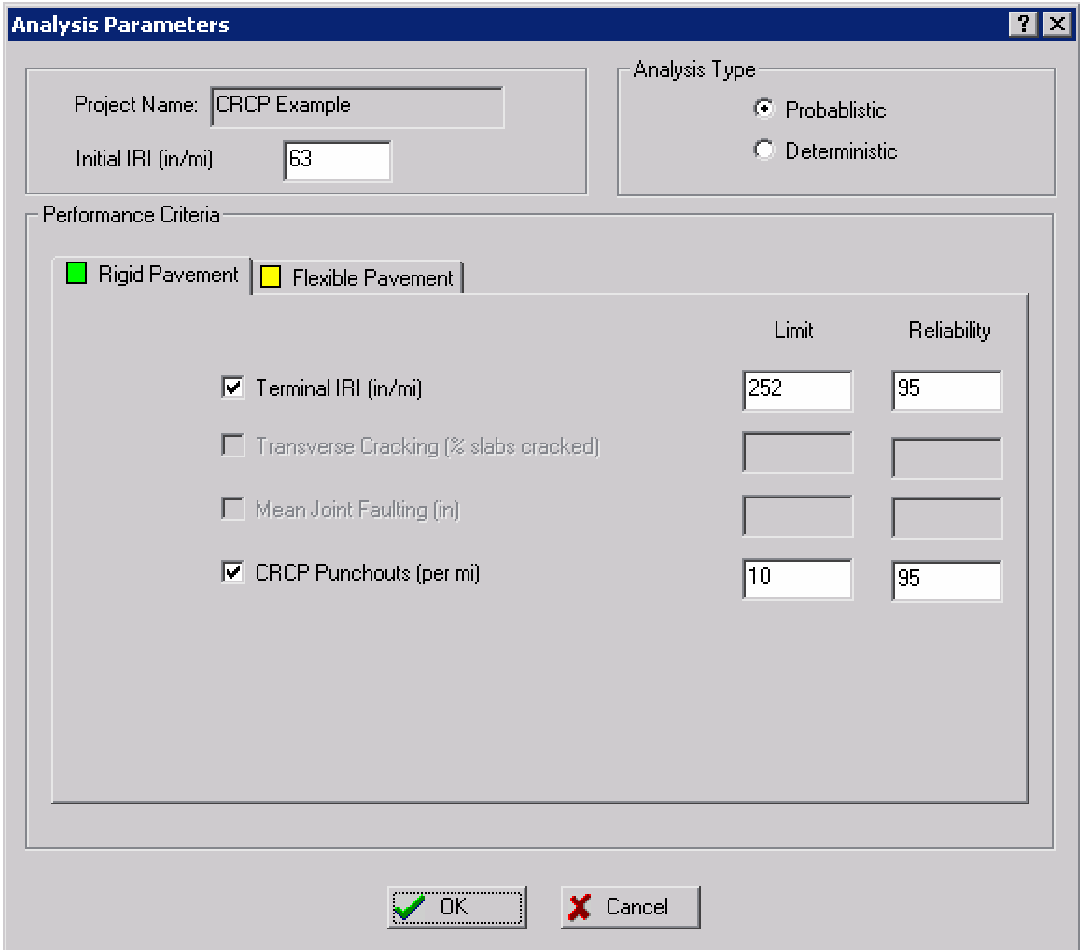


Figure D.55. *Analysis Parameters* screen for CRCP.

Click *OK* and return to the main layout program. Note that the icons in the general inputs are all green at this point. It is suggested that at this point, the input file be saved by clicking on the diskette icon in the tool bar or by clicking *Save* on the *File* menu

D.3.3 Traffic Inputs

<u>D.3.3.1 *Traffic*</u>

This screen allows the user to make general traffic volume inputs and also provides a link to other traffic screens for Volume Adjustments, Axle Load Distribution Factors, and General Inputs. Please note that these screens can also be accessed from the main layout screen. Inputs on this screen, as shown in Figure D. 56 are as follows:

Two way average annual truck traffic: 2250
Number of lanes in design direction: 2
Percent of trucks in design direction: 50
Percent of trucks in design lane: 90
Operational truck speed: 60

Note that the chosen design life and the date of opening to traffic appear on this screen. Also note the links to *Traffic Volume Adjustment*, *Axle Load Distribution*, and *General Traffic Inputs* screens. These are the three main categories of traffic inputs required for the design and individual links to these screens are also available from the main program layout.

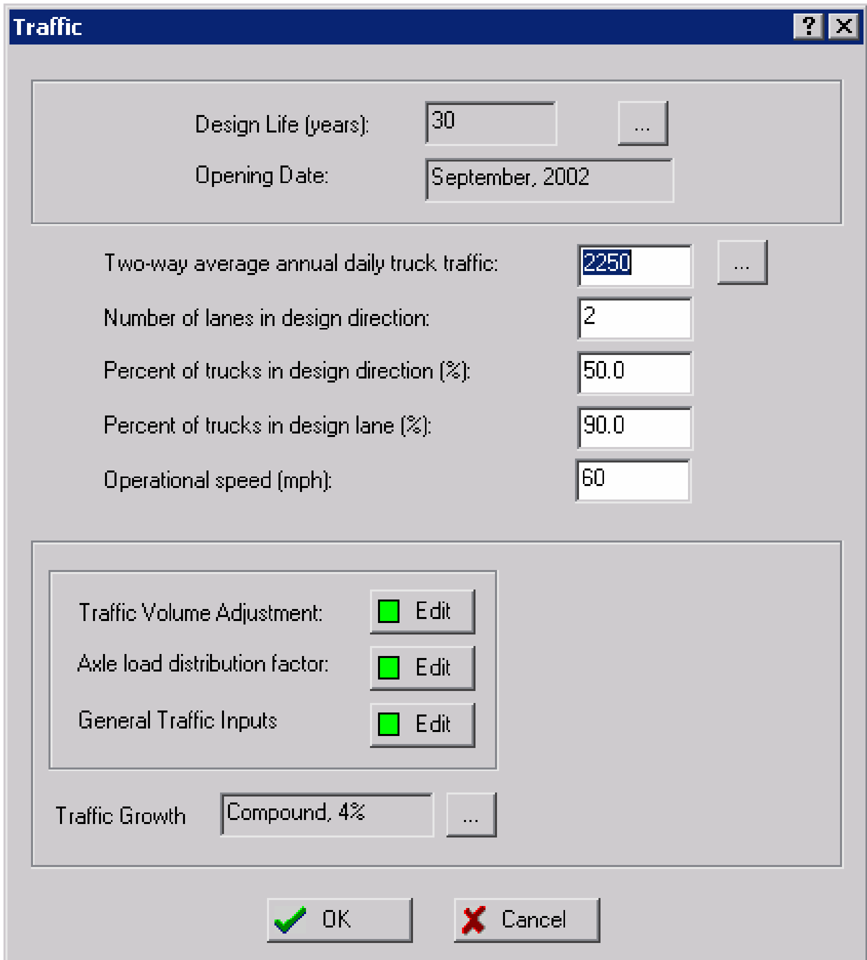


Figure D. 56. *Traffic* screen.

Click *OK* and return to the main layout program.

<u>D.3.3.2. *Traffic Volume Adjustment Factors*</u>

The Traffic Volume Adjustment Factors screen has 4 property pages (or sub-screens), namely:

- *Monthly Adjustment*
- *Vehicle Class Distribution*
- *Hourly Distribution*
- *Traffic Growth Factors*

D.3.3.2.1 *Monthly Adjustment*

The inputs on this screen indicate the distribution of traffic over the different months of a year for each traffic class. The Monthly Adjustment Factor (MAF) is the proportion of AADTT occurring over a 24-hour period in each month for each vehicle class.

For this example, since the traffic distribution remains the same through out the year, i.e. does not change between the different months of the year, the default monthly adjustment factors can be used.

Click on the radio button for Level 3 default inputs as shown in Figure D.57. Note that the default MAF value is 1.0 for all months in each vehicle class.

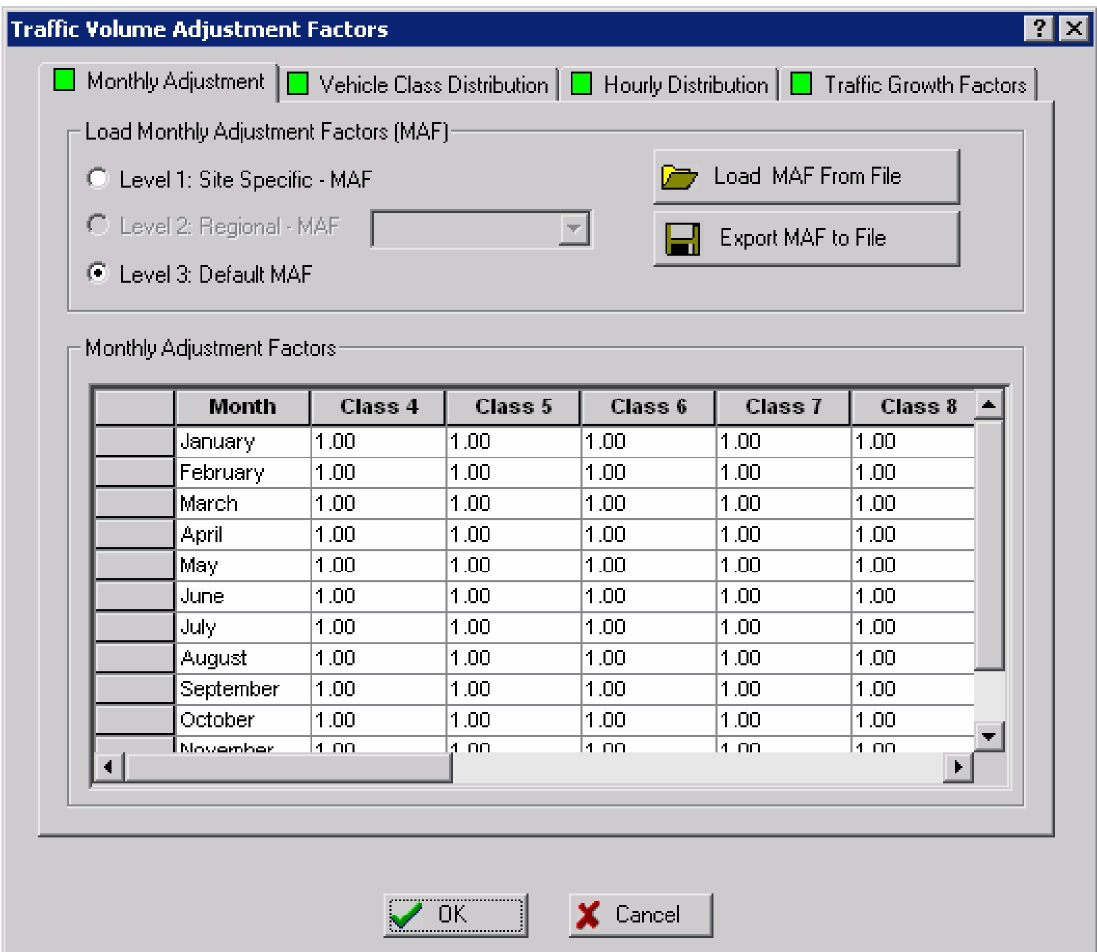


Figure D.57. *Monthly Adjustment Factors* screen.

Next click on the *Vehicle Class Distribution* tab.

D.3.3.2.2 *Vehicle Class Distribution*

Site-specific vehicle class distribution data is available for this design project. Click on the radio button *Level 1: Site Specific Distribution* and enter the distribution as shown in Figure D. 58.

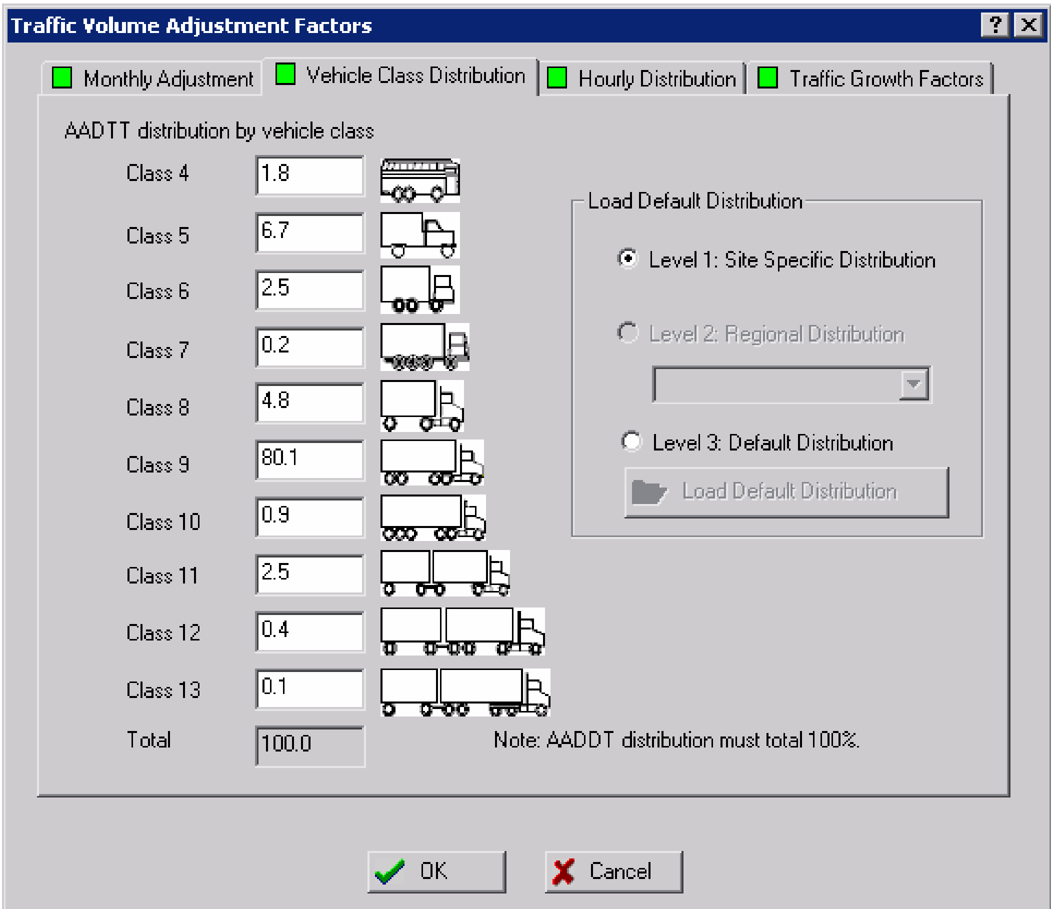


Figure D. 58. *Vehicle Class Distribution* screen.

Next, click on the *Hourly Distribution* tab.

D.3.3.2.3 *Hourly Distribution*

Enter the hourly distribution of the AADTT as shown in Figure D.59. Next, click on the *Traffic Growth Factors* tab.

D.3.3.2.4 *Traffic Growth Factors*

The given data suggests that the traffic grows 4.0 % at a compound rate. The program will use a default function for traffic growth at a compound rate. Select *Compound Growth* and enter a growth rate of 4.0 % as shown in Figure D.60.

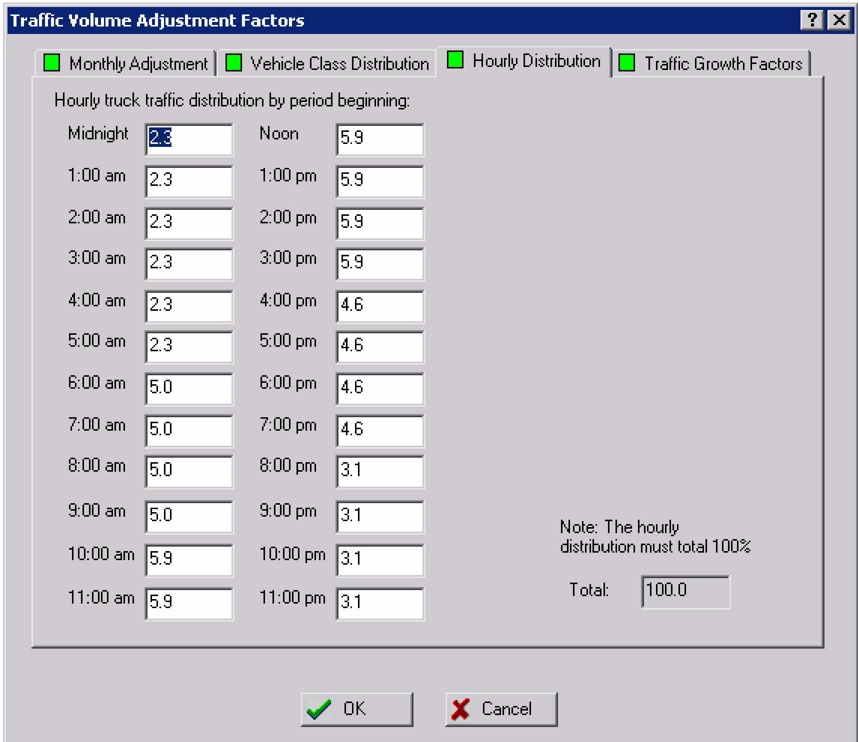


Figure D.59. *Hourly Distribution* screen.

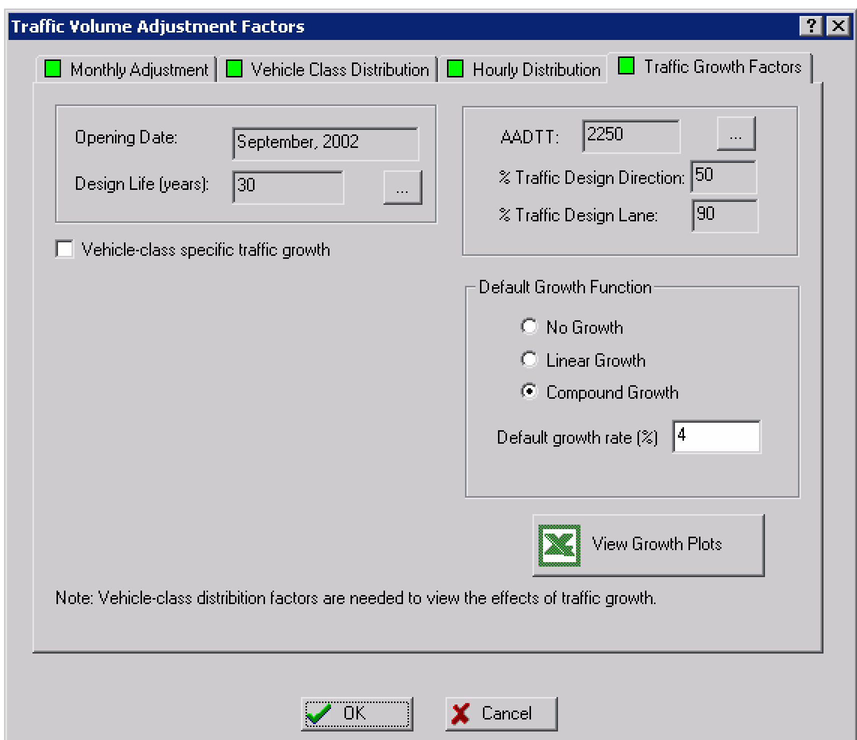


Figure D.60. *Traffic Growth Factors* screen.

Next click on *View Growth Plots* to open a Microsoft Excel spreadsheet that shows the growth in AADTT for each vehicle class over the design life. The plots are shown in Figure D.61, Figure D.62 and Figure D.63.

Close the Excel spreadsheet and click *OK* on the *Volume Adjustments* screen to return to the main layout page.

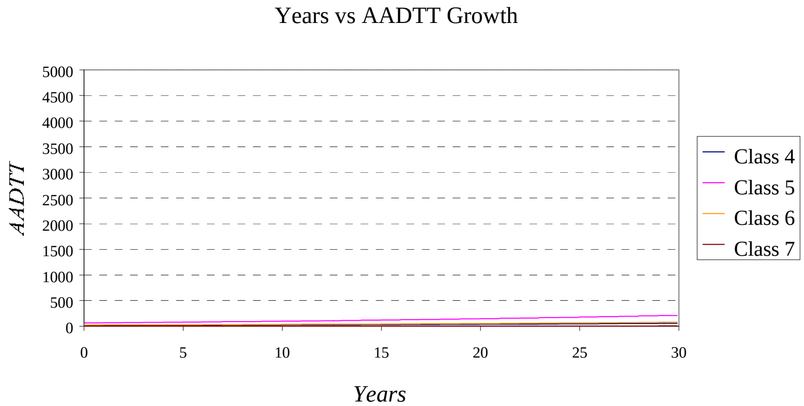


Figure D.61. Growth in AADTT for Vehicle classes 4 through 7.

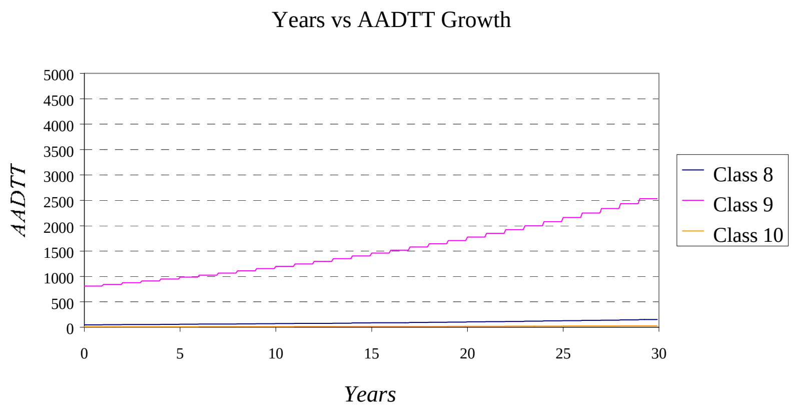


Figure D.62. Growth in AADTT for Vehicle classes 8 through 10.

D.3.3.3 *Axle Load Distribution Factors*

This screen allows the user to specify the percentage of vehicles in each vehicle class, at each load level, for each axle type. This design example uses the default LTPP distribution and therefore the level 3-default input will be used. Click on the radio button for level 3 axle load distribution factors as shown in Figure D. 64. The program automatically loads default values for these inputs. Click *Ok* to return to the main screen.

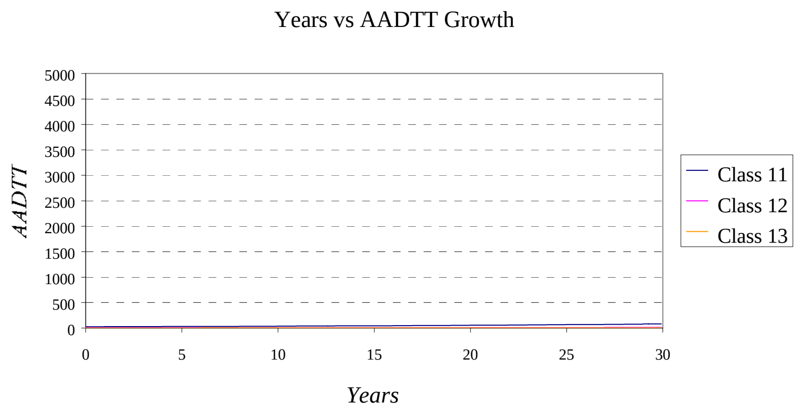


Figure D.63. Growth in AADTT for Vehicle classes 11 through 13.

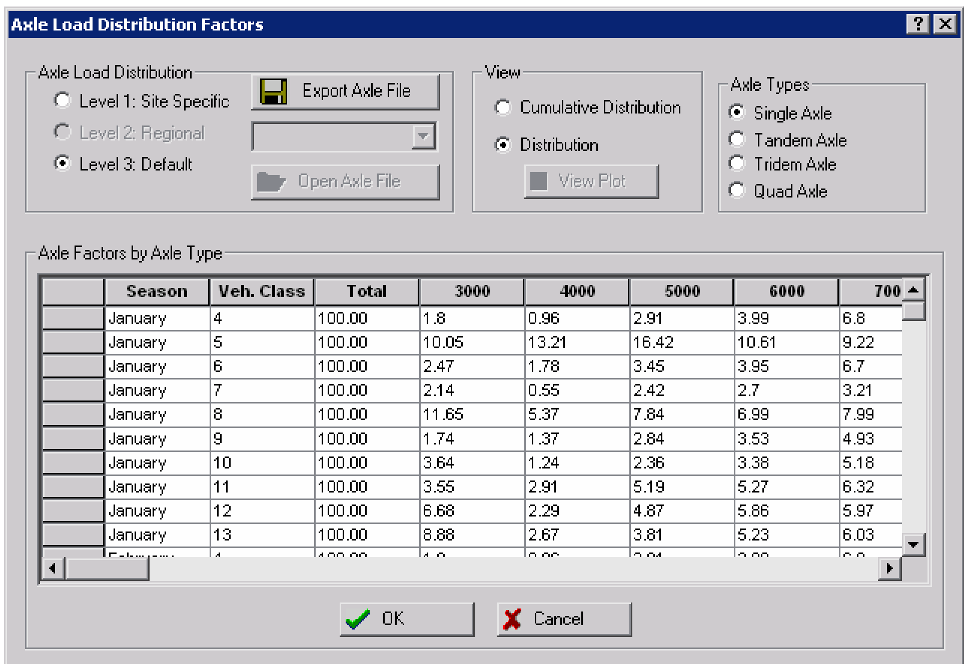


Figure D. 64. *Axle Load Distribution Factors* screen.

D.3.3.4 *General Traffic inputs*

This screen allows the user to provide traffic wander inputs and also has 3 property pages, namely,

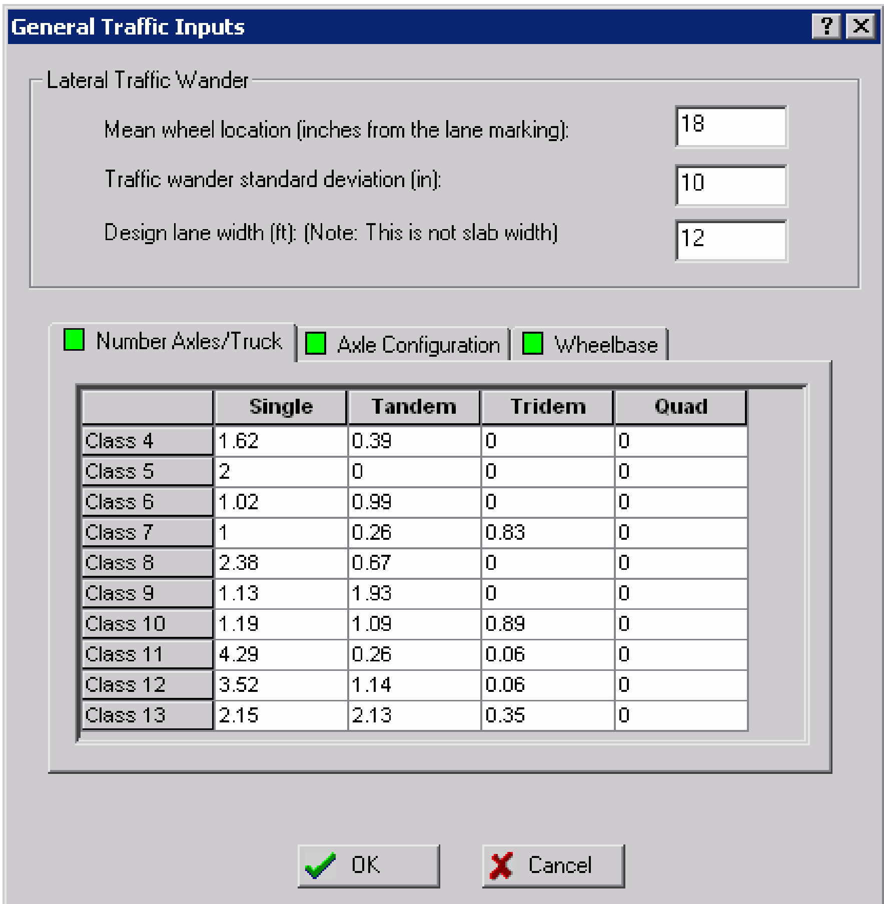
Number of Axles/Truck
Axle Configuration
Wheelbase

Enter the following inputs with regard to lateral traffic wander as shown on Figure D. 65
Mean wheel location: 18

Traffic wander standard deviation: 10
Design lane width: 12

D.3.3.4.1 *Number Axles/Truck*

Enter the number of axles per truck as shown in Figure D. 65:



	Single	Tandem	Tridem	Quad
Class 4	1.62	0.39	0	0
Class 5	2	0	0	0
Class 6	1.02	0.99	0	0
Class 7	1	0.26	0.83	0
Class 8	2.38	0.67	0	0
Class 9	1.13	1.93	0	0
Class 10	1.19	1.09	0.89	0
Class 11	4.29	0.26	0.06	0
Class 12	3.52	1.14	0.06	0
Class 13	2.15	2.13	0.35	0

Figure D. 65. *General Traffic* Inputs – *Number of Axles/Truck* screen.

D.3.3.4.2 *Axle Configuration*

Enter the following inputs on the *Axle Configuration* property page as shown in Figure D. 66:

Average axle width: 8.5
Dual tire spacing: 12
Tire pressure:
    Single tire: 120
    Dual tire: 120
Axle spacing:
    Tandem axle: 51.6

Tridem axle: 49.2
Quad axle: 49.2

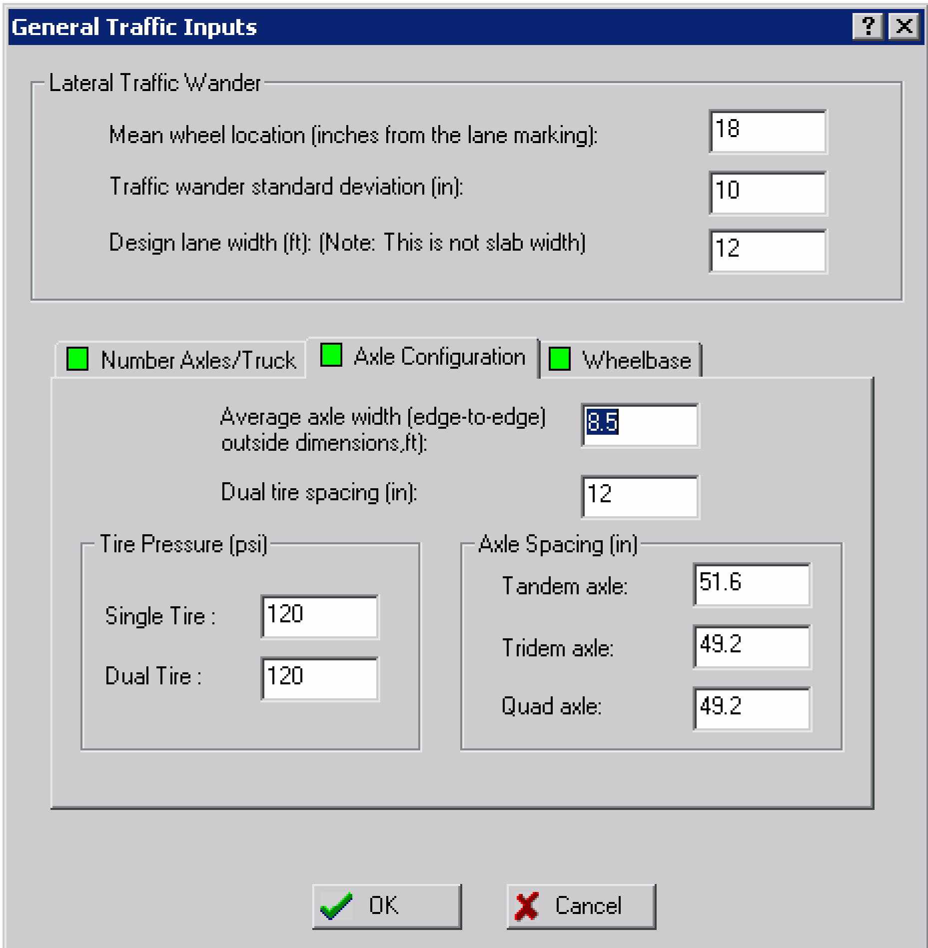


Figure D. 66. *General Traffic Inputs – Axle Configuration* screen.

D.3.3.4.3 *Wheelbase*

Enter the following inputs on the *Wheelbase* property page as shown in Figure D. 67:

Average axle spacing
- Short: 12
- Medium: 15
- Long: 18

Percentage trucks (inputs not used for CRCP analysis)
- Short: 2.0
- Medium: 20.0
- Long: 78.0

Click *OK* and return to the main program layout screen. The user, by this stage, has made all traffic inputs and is now ready to make Climate inputs for the project. Save the project file before proceeding.

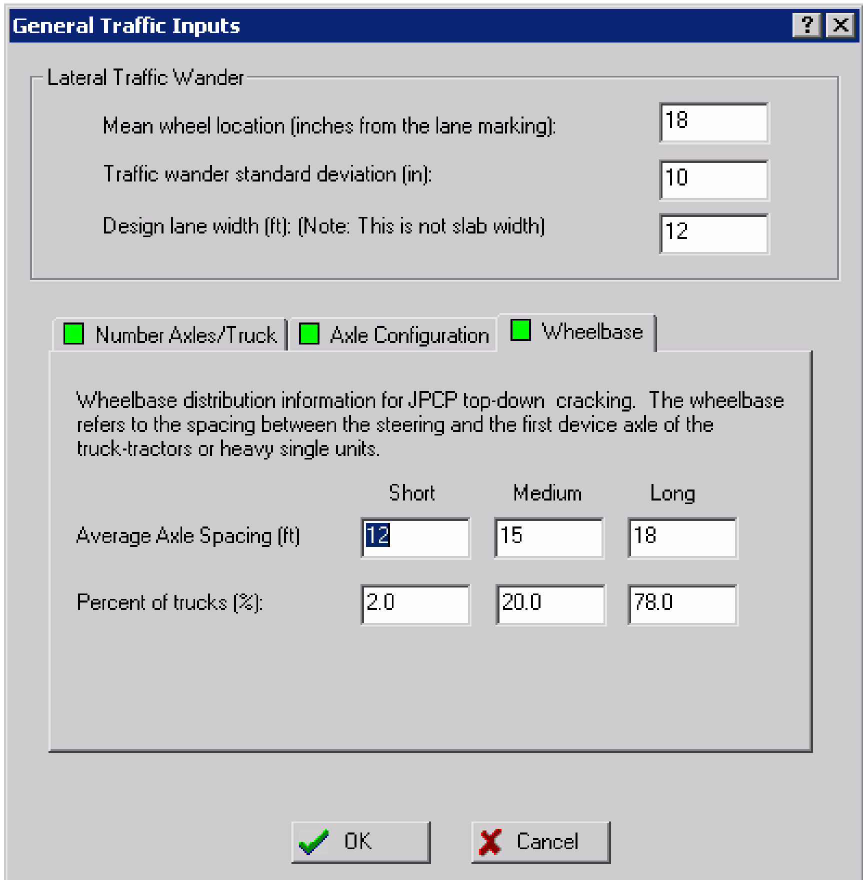


Figure D. 67. *General Traffic* Inputs – *Wheelbase* screen.

D.3.4 Climate Inputs

<u>D.3.4.1 *Climate*</u>

This design example provides very specific location information for the project site, the latitude, longitude, and elevation. With this information available, it will be possible to develop climate data file for this project. Click on *Climate* on the main project layout screen. On the main *Climate* screen, as shown in Figure D. 68, click on *Generate* to generate a new climatic data file.

The program now opens a new screen allowing the user to make inputs for the location coordinates. As shown in Figure D. 69, enter the following:

Latitude: 39.90
Longitude: -88.30
Elevation (feet): 700
Depth of water table (feet): 10

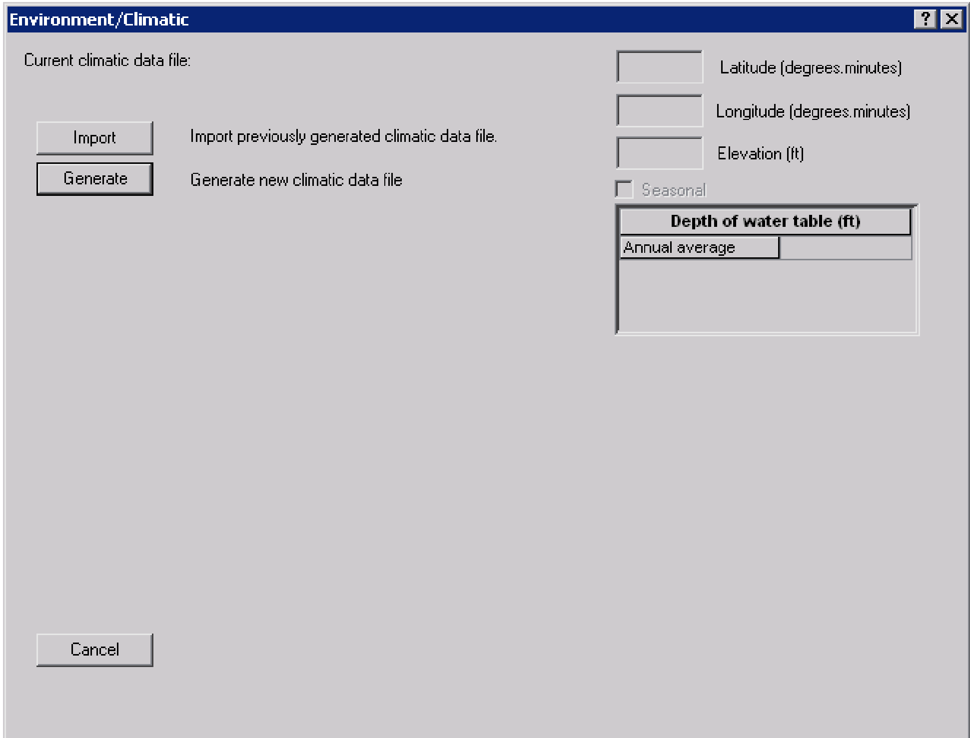


Figure D. 68. Main *Climate* screen.

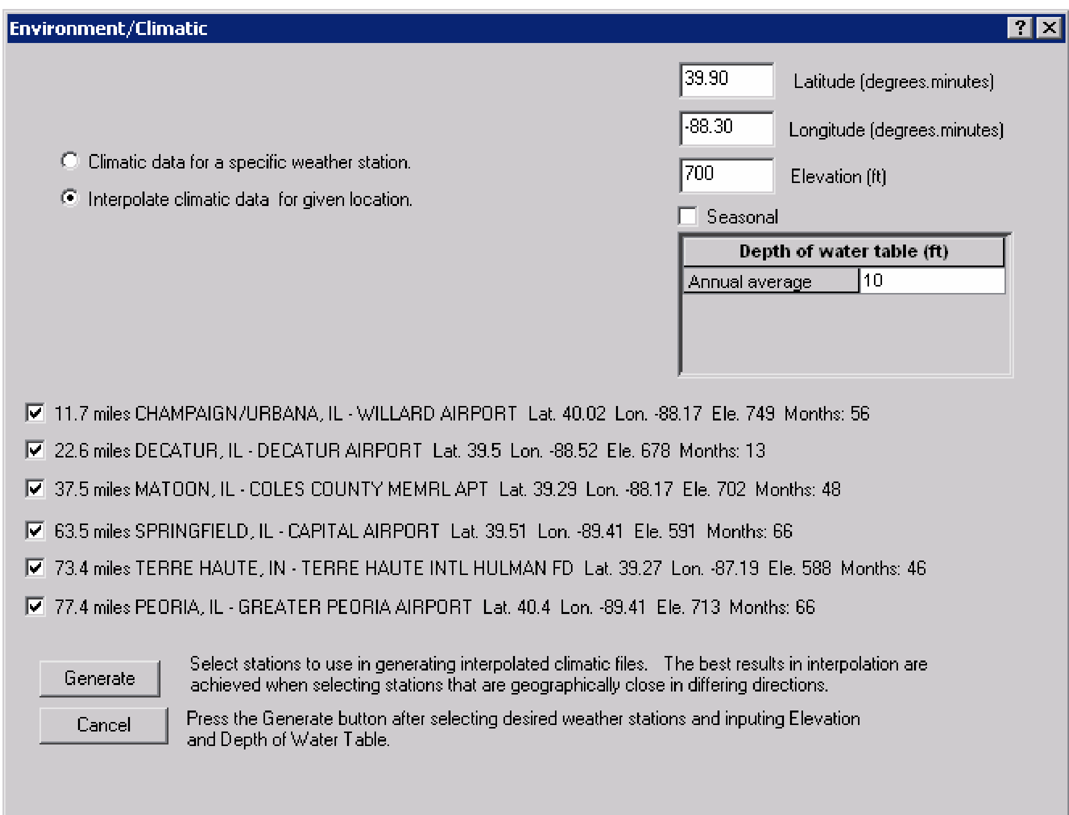


Figure D. 69. Generating climatic data file for the project location.

On entering the location coordinates for the project site, the program automatically lists the six closest weather stations in the database that is within a radius of 100 miles. Climatic data is interpolated from those weather stations that are selected on this screen.

It is important to recognize that the design engineer needs to make a sound judgment call in selecting the weather stations that are most indicative of the weather conditions at the project site, rather than routinely select all 6 sites for interpolation. The basis for selecting weather stations will vary from project to project. Also, the extent of weather data available at a given weather station is an important factor in selecting weather stations in generating interpolated climatic file. In general, it is recommended that as many weather stations as possible be selected to generate a virtual weather station.

For the purpose of this example, select all weather stations and click on the *Generate* button. The program creates the climatic data file for the project. After the climatic data file is created, the program prompts the user to save it. Save the file in the project directory - *"C:\DG2002\Projects\CRCP EXAMPLE\crcp.icm"*.

Note that the program also automatically creates a file called *climate.tmp* in the project directory. This is the file that the program reads hourly climatic information from during the analysis stage. This file contains the sunrise time, sunset time and radiation for each day of the design life period. In addition, for each 24-hour period in each day of the design life, the temperature, rainfall, air speed, sunshine, and depth of ground water table are also listed in the climate file.

By this stage, the user has completed the climatic inputs required by the program. The color-coded icons will have a green color for the traffic and climate and red icons for structure, indicating that the traffic and climate inputs are complete and structural inputs are yet to be addressed.

D.3.5 Structural Inputs

The user at this stage needs to choose structural parameters and a layer combination that can be evaluated for its performance. As explained in the PART 3 of the Guide, the procedure is an iterative procedure and the user will have to develop a trial design and make several modifications to it, before a feasible and economic (or final) design is achieved.

Choose the following layers in the trial design for the given CRCP example

- 9.0-in CRCP layer
- 4.0-in asphalt concrete base layer
- 12.0-inccompacted subgrade layer
- Semi-infinite uncompacted (natural) subgrade layer

The structural inputs are of three categories, *CRCP Design Features*, *Drainage and Surface Properties*, and *Layer Properties*. These three categories of inputs have direct links from the main program layout screen.

D.3.5.1 *Design Features*

Click on the *Design Features* link on the main program layout screen and the program opens a screen to enable inputs for CRCP Design Features. The inputs to be made on this screen are shown in Figure D. 70.

The default slab thickness (which can be edited on the layers screen discussed in 2.5.3.1) appears on the screen on a non-edit mode. Choose the *Shoulder type* from the scroll-down menu. Select *Asphalt* for an Asphalt shoulder. Enter a value of 10 for *permanent curl/warp effective temperature difference*.

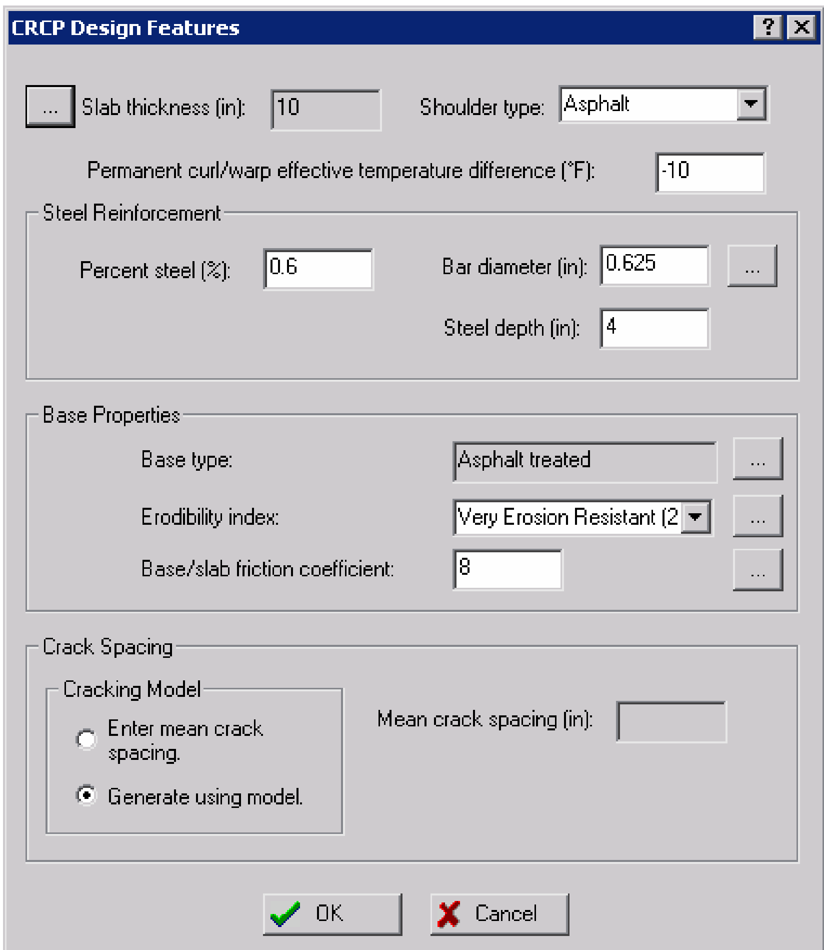


Figure D. 70. *CRCP Design Features* screen.

Next, the steel reinforcement chosen for the CRCP trial design is to be entered. For the given trial design, 0.6% steel comprising of 5/8" diameter steel bar at 4-inch depth is suggested.

Because the chosen base layer is an asphalt concrete base layer, choose an erodibility index of 2 representing a very erosion resistant base layer. The suggested base/slab friction coefficient for this example is 8.0.

The user can either choose to use the cracking model built in the program to generate crack spacing or can enter the expected mean long-term crack spacing. Click the radio button *Generate using model* to allow the program to predict mean crack spacing. Finally, click *Ok* and return to the main program layout.

D.3.5.2 *Drainage and Surface Properties*

From the main program layout screen click on *Drainage and Surface Properties* to open the screen shown in Figure D. 71.

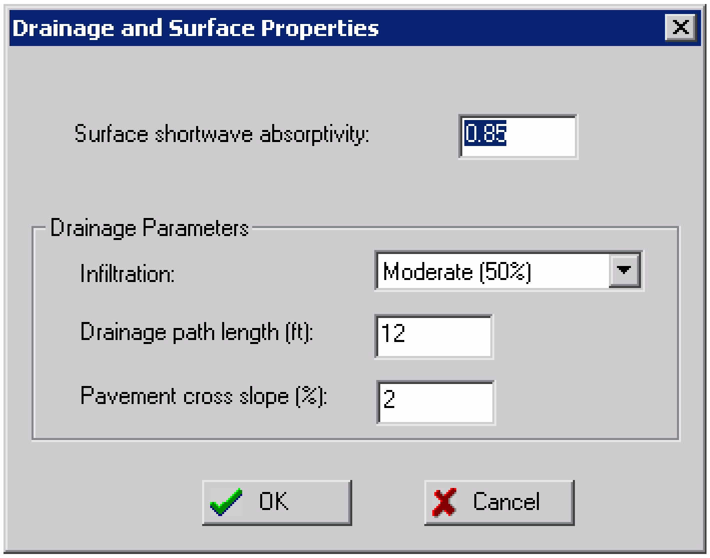


Figure D. 71. *Drainage and Surface Properties* screen.

Enter 0.85 for *surface shortwave absorptivity*. For an asphalt shoulder, the recommended infiltration is 50% corresponding to a *moderate* level of infiltration. Enter 12 feet for the D*rainage path length* and 2 percent for P*avement cross slope*. Click *Ok* and return to the main program layout.

D.3.5.3 *Layers*

On the main program layout screen, click on *Layers* to add and edit pavement layers in the trial design. The program opens the Layers screen as shown in Figure D. 72. The three main functions this screen allows the user to perform are:

- Inserting a layer after a selected layer – by clicking the *Insert* button
- Deleting a selected layer – by clicking the *Delete* button
- Editing the layer properties of a selected layer – by clicking the *Edit* button

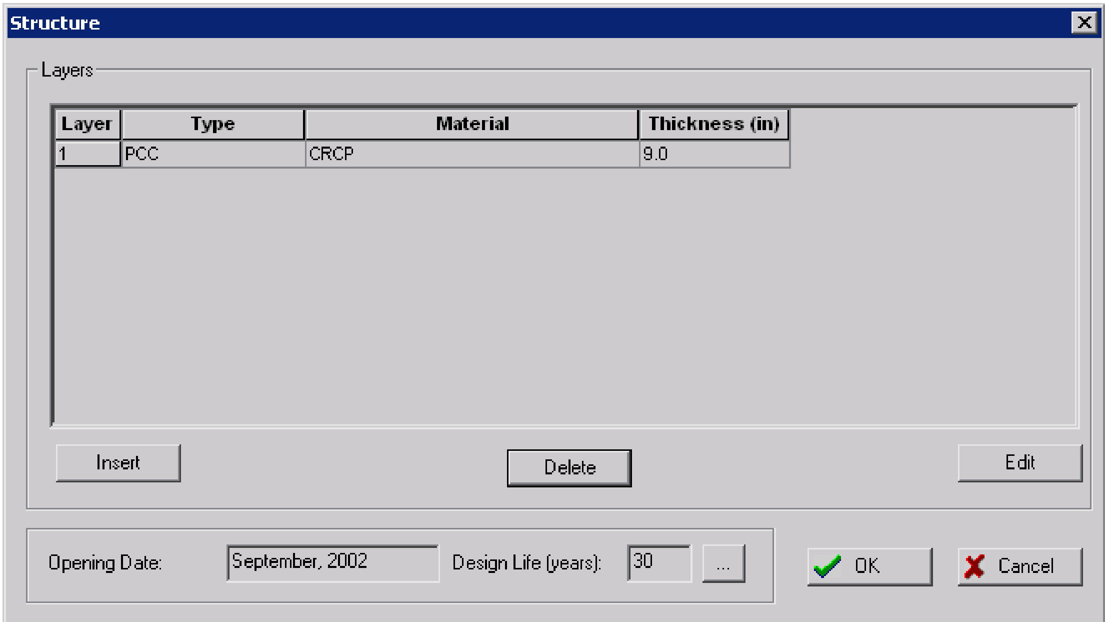


Figure D. 72. *Layers* screen.

The first layer of the pavement, the PCC layer is shown on the screen in Figure D. 72. Next, the user has to add a layer after (underneath) the PCC layer. To add a layer after the PCC layer, select layer 1 by clicking on the row shown for Layer 1 and then insert a layer by clicking on the *Insert* button. The program now opens a screen shown in Figure D. 73 that allows the user to select the layer to be added.

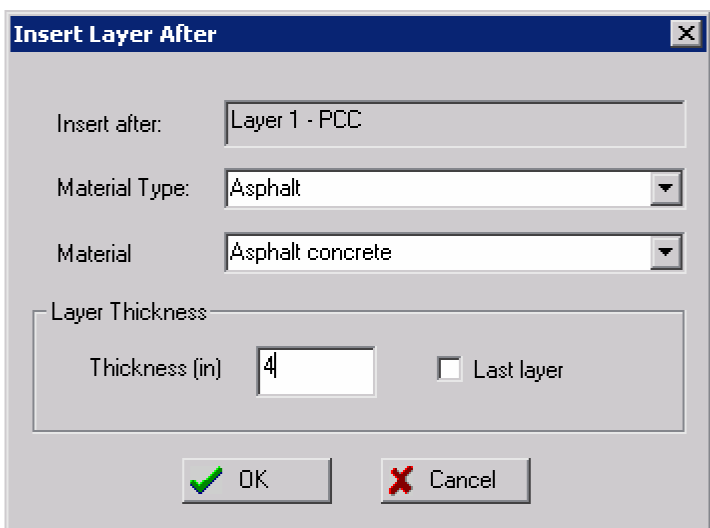


Figure D. 73. Inserting asphalt layer after the PCC layer.

From the scroll down menu, select Asphalt for the M*aterial type* and Asphalt concrete for the *Material.* Enter a thickness value of 4 and click *Ok* to return to the *Layers* screen shown in Figure D. 74. This screen now shows the newly added asphalt concrete layer.

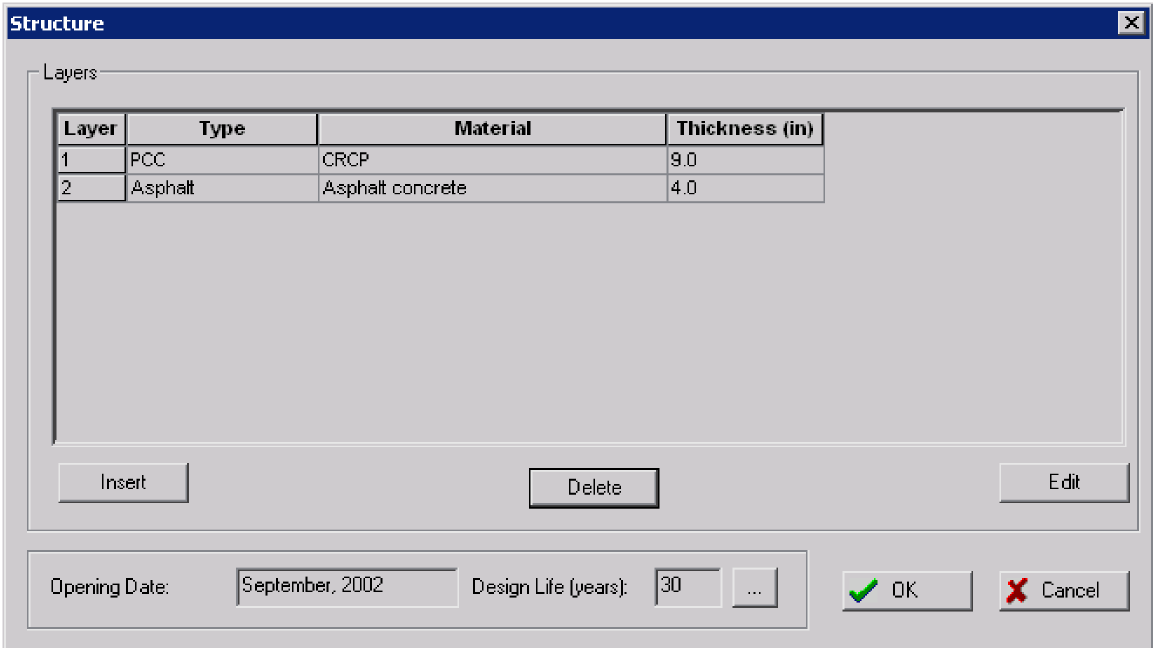


Figure D. 74. *Layers* screen after inserting the base layer.

Next, select layer 2 and click *Insert* to add a layer after the asphalt layer. Select Subgrade for the *Material type* and ML for *Material* (ML is representative of fine-grained soils, sandy lean clay per the Unified Classification system) as shown in Figure D. 75. Enter a thickness of 12 inches Click *Ok* and return to the *Layers* screen.

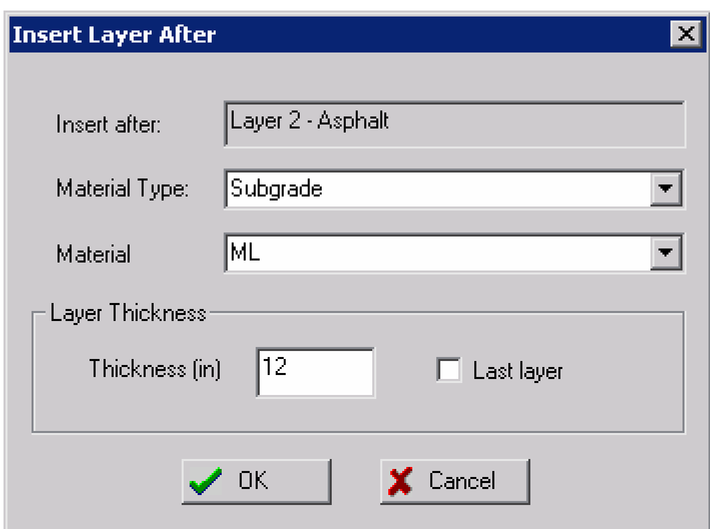


Figure D. 75. Inserting the compacted subgrade layer after the asphalt base layer.

It is recommended that the subgrade layer be entered as two layers to represent the semi-infinite subgrade and a layer above with compacted subgrade material. Please note that if the user fails to enter two distinct layers and chooses only one subgrade layer instead, the program will automatically prompt the user to add a second layer so that the drainage prediction model will function properly.

Repeat the same steps again and add the last layer as shown in Figure D. 76. Select the *last layer* option instead of entering a thickness to this layer. Click *Ok* and return to the Layers screen that now has all four layers added to the structure as shown in Figure D. 77.

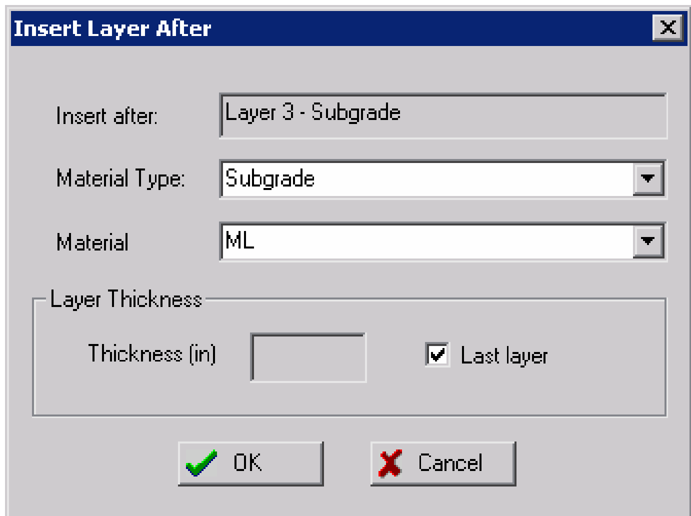


Figure D. 76. Inserting the uncompacted subgrade layer after the compacted subgrade.

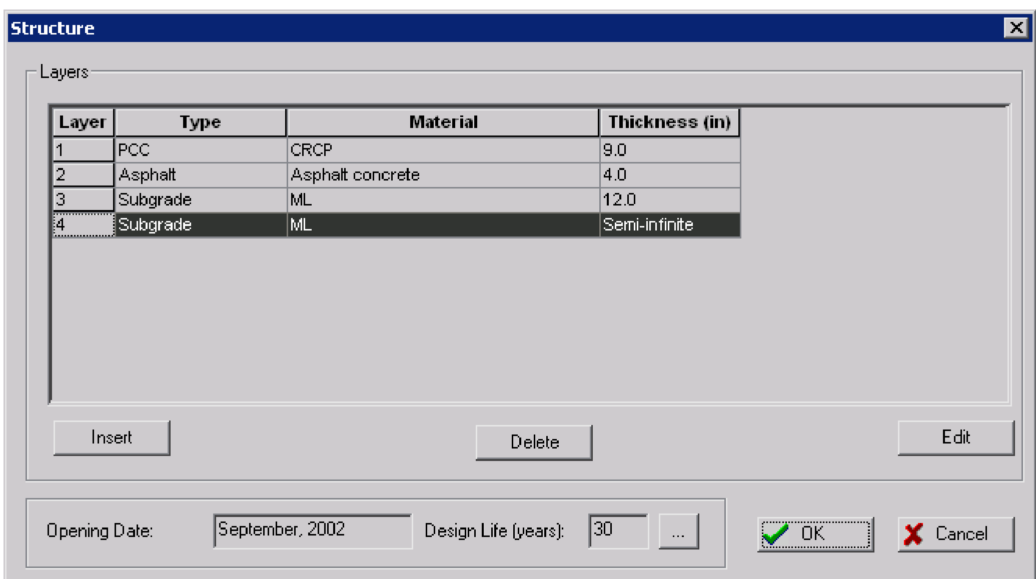


Figure D. 77. Layers screen after the addition of all layers.

The individual screens for the input of layer material properties can be accessed either from the *Layers* screen shown in Figure D. 77, or directly from the program layout screen. To access the material properties screen from the *Layers* screen, select the desired pavement layer and click on *Edit*. To return to the program layout screen, click *Ok* on the *Layers* screen. The program layout screen now, as shown in Figure D. 78.

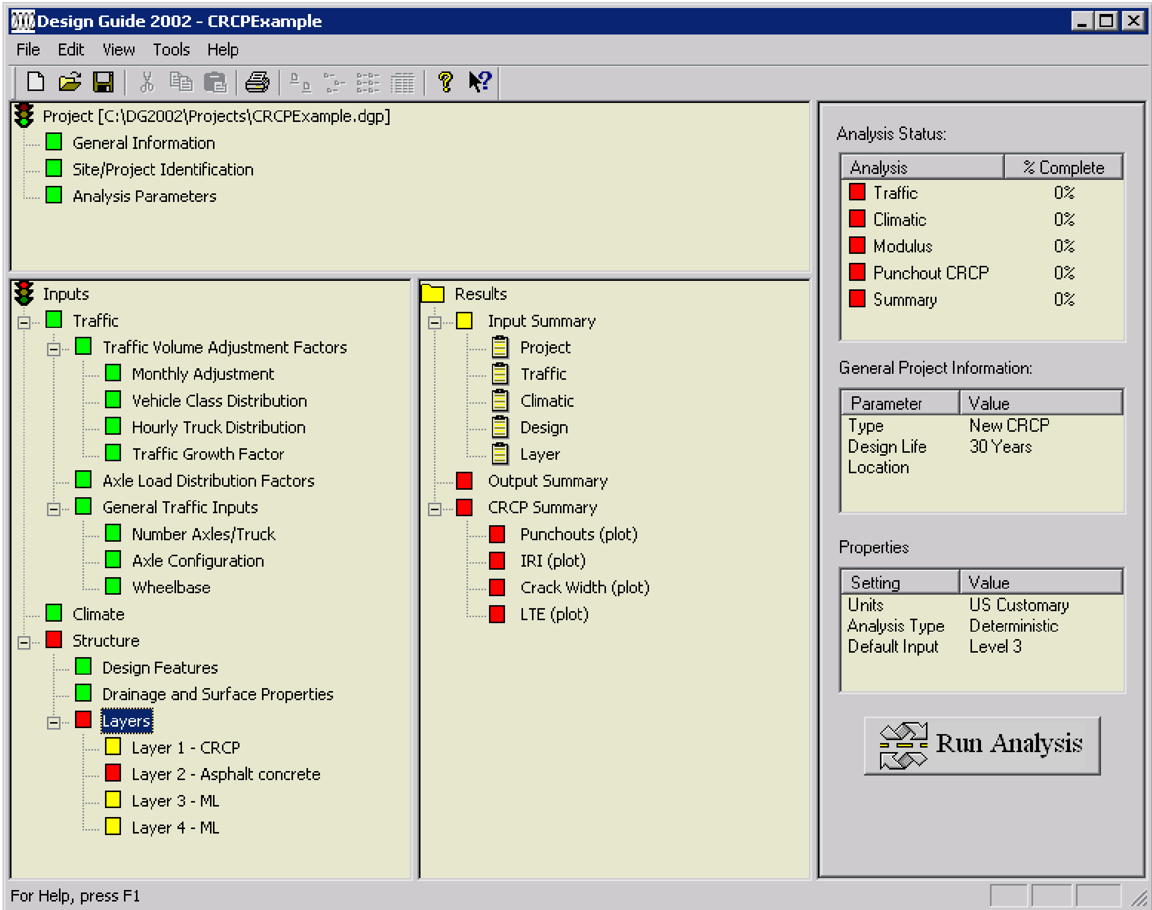


Figure D. 78. Program layout screen after adding all layers.

D.3.5.3.1 *Layer 1 – CRCP*

Click on *Layer 1 – CRCP* to edit PCC layer material properties. This opens a screen with three property pages for *Thermal*, *Mix*, and *Strength* properties. On the Thermal properties screen, as shown in Figure D. 79, enter the following inputs:

Layer thickness = 9 inches
Unit weight = 145 pcf
Poisson's ratio = 0.20
Coefficient of thermal expansion = 6.3 in/in/^{o}F
Thermal conductivity = 1.25 BTU/hr-ft-^{o}F
Heat capacity = 0.28 BTU/lb-^{o}F

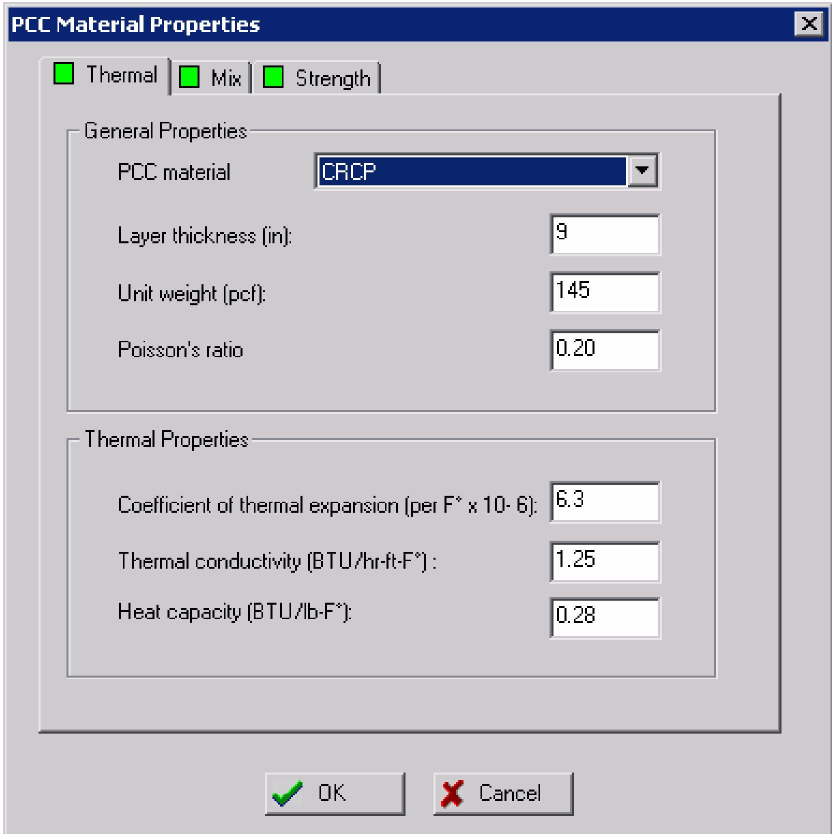


Figure D. 79. *PCC Material Properties – Thermal Properties* screen.

Next, click on the *Mix* tab and move to the property page requiring inputs specific to the mix. As shown in Figure D. 80, the following inputs are made:

Cement Type : Type 1 (from draw down menu)
Cement content: 565 lb/yd^3
Water cement ratio: 0.402
Aggregate type: Dolomite (from the draw down menu)
Reversible Shrinkage: 50%
Time to develop 50% of ultimate shrinkage: 35 days
Curing method: Curing compound (from draw down menu)

Next, click on the *Strength* tab and move on to the property page requiring inputs for concrete strength properties. This screen is shown in Figure D. 81. Click the radio button corresponding to level 1 inputs. The screen provides an array format to enter the strength and modulus values at different ages. Enter values as shown in Figure D. 81. Note that the compressive strength inputs are not required for level 1 inputs. However, level 2 inputs would require only the compressive strength values at all ages.

Click *Ok* and return to the program layout screen. Note that the icon for Layer 1 is now green.

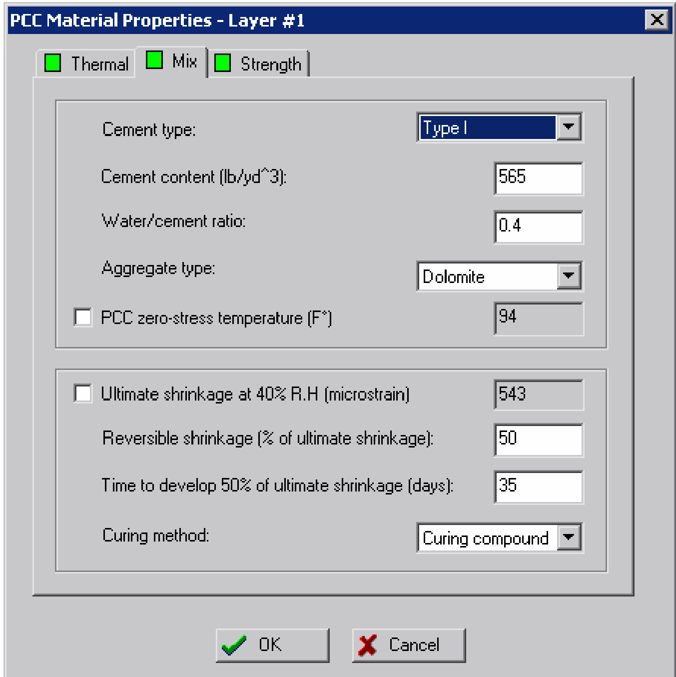


Figure D. 80. *PCC Material Properties – Mix Properties* screen.

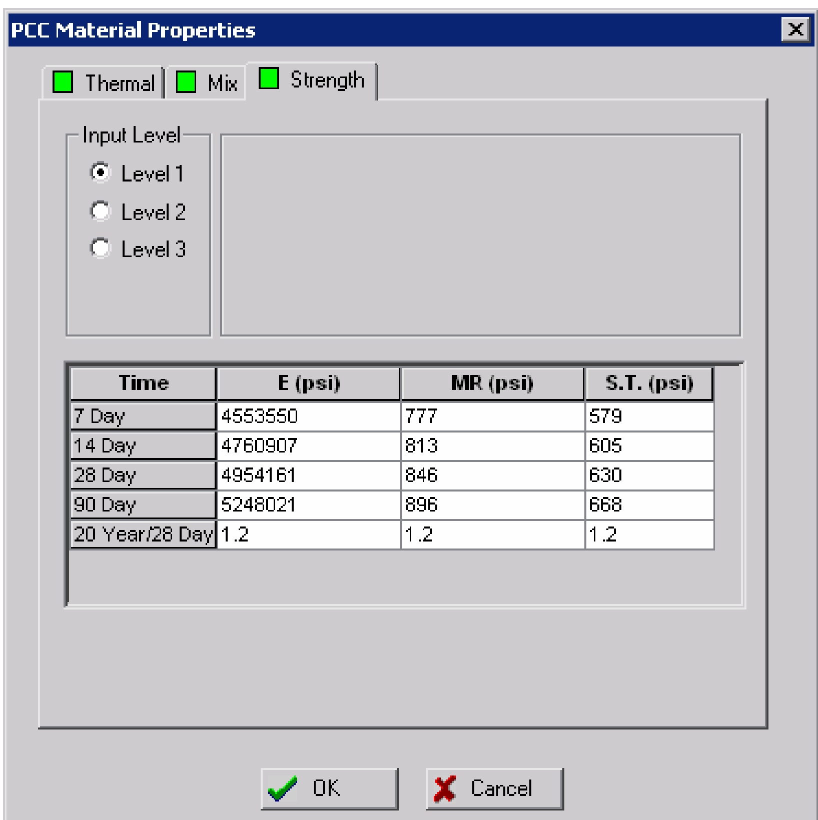


Figure D. 81. *PCC Material Properties –Strength Properties* screen, level 1.

D.3.5.3.2 *Layer 2 – Asphalt Concrete*

Click on Layer 2 on the program layout screen and choose level 3 inputs from the scroll down menu. The chosen material type and thickness appear on the screen (Note that this information can be modified on this screen). The asphalt material properties screen has three property pages – *Asphalt Mix, Asphalt Binder, Asphalt General* - as shown in Figure D. 82, Figure D. 83, and Figure D. 84.

On the asphalt mix screen enter the gradation of the aggregate used in asphalt concrete. Assume the following gradation for this design example

Cumulative % Retained 3/4 inch sieve: 0
Cumulative % Retained 3/8 inch sieve: 35
Cumulative % Retained #4 sieve: 50
% Passing #200 sieve: 5

After completing the above inputs on the A*sphalt Mix* properties screen as shown in Figure D. 82, click on the *Asphalt Binder* tab and make the following selections as shown in Figure D. 83

Option: Conventional viscosity grade
Viscosity Grade: AC-20

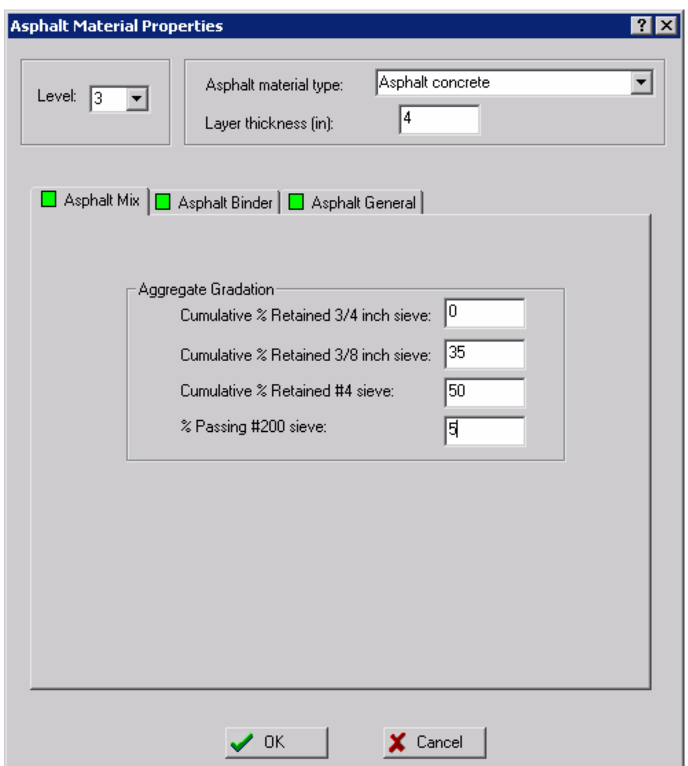


Figure D. 82. *Asphalt Material Properties* screen – *Asphalt Mix* property page.

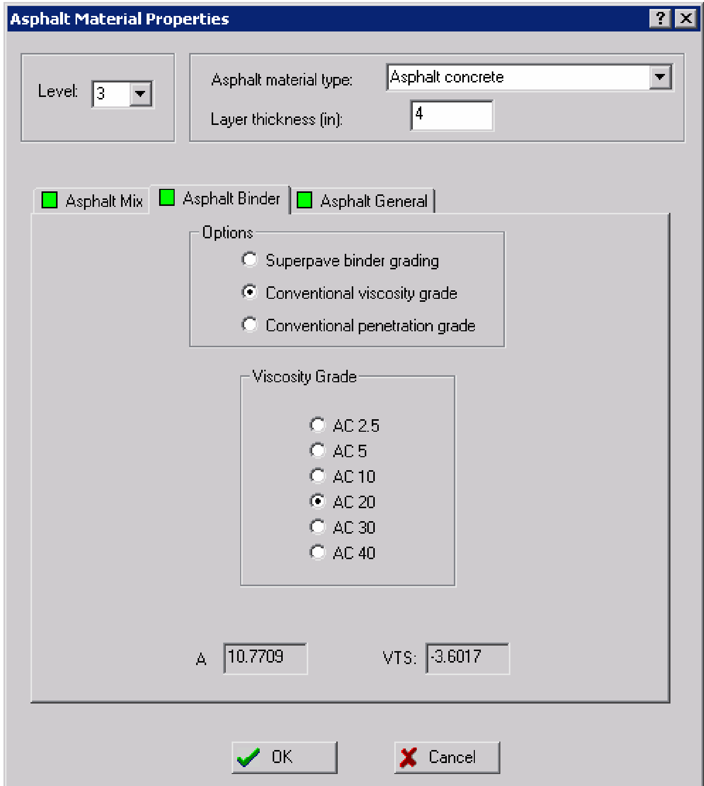


Figure D. 83. *Asphalt Material Properties* screen – *Asphalt Binder* property page.

Next, click on the *Asphalt General* tab and make the following inputs for this example as shown in Figure D. 84:

General
- Reference temperature (F°): 70
- Design frequency (Hz): n/a

Volumetric Properties
- Effective binder content (%): 11
- Air voids (%): 8.5
- Total unit weight (pcf): 148

Poisson's ratio: 0.35 (user entered)

Thermal Properties
- Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
- Heat capacity asphalt (BTU/lb-F°): 0.23

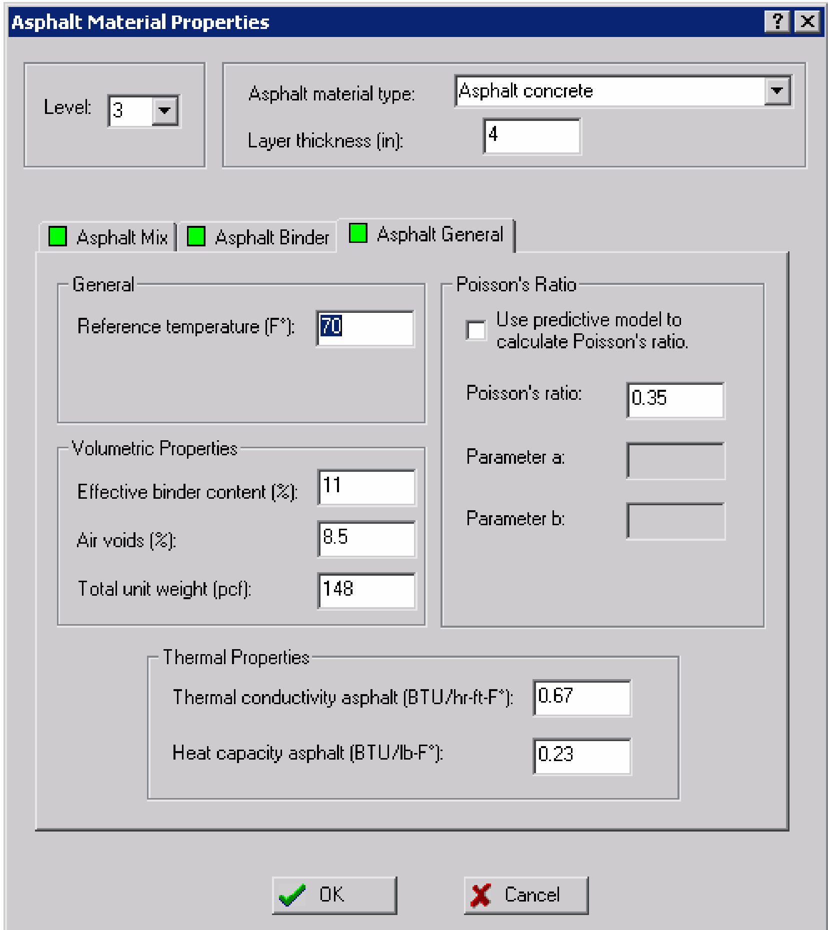


Figure D. 84. *Asphalt Material Properties – Asphalt General* screen.

Click *Ok* and return to the main program layout screen. Note that the icon adjacent to *Layer 2 – Asphalt concrete* layer is now green in color because of inputs being complete in this layer.

D.3.5.3.3 *Layer 3 – ML*

Click on *Layer 3 – ML* on the program layout screen to enter inputs for the subgrade layer. The screen that enables the user to make inputs for an unbound layer opens as shown in Figure D. 85. Note that the choice made for the unbound material type and the layer thickness appear on the screen. (This screen also allows the user to make changes to these choices if necessary).

Choose the radio button corresponding to level 3 inputs, which requires only the input for modulus for material property. Enter the following input values:

Poisson's ratio: 0.35
Coefficient of lateral pressure: 0.50
Resilient Modulus (psi): 20,000

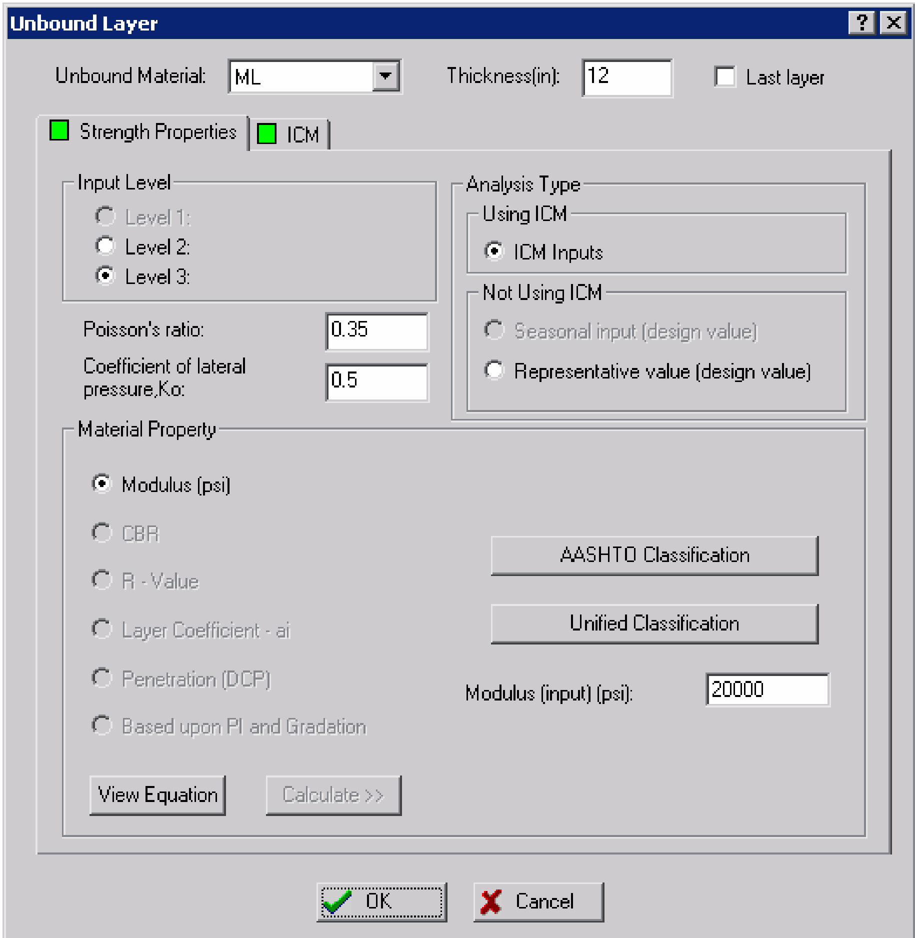


Figure D. 85. *Subgrade (Unbound) layer* screen – *Strength Properties* page.

For *Analysis Type*, click on the radio button adjacent to *ICM Inputs* to indicate that the user will make ICM inputs to the program. Next, click on the ICM tab to make ICM inputs. The inputs made on this screen, shown in Figure D. 86, are as follows:

Plasticity Index, PI: 15
Passing #200 sieve (%): 68.5
Passing #4 sieve (%): 97
D60 (mm): 0.0265

Since layer 3 is the 12-inch compacted subgrade layer above the natural subgrade, click on the radio button corresponding to *Compacted unbound material*. Click on *Update* to view the various parameters that are calculated or derived by ICM.

Click *OK* and return to the main program layout screen.

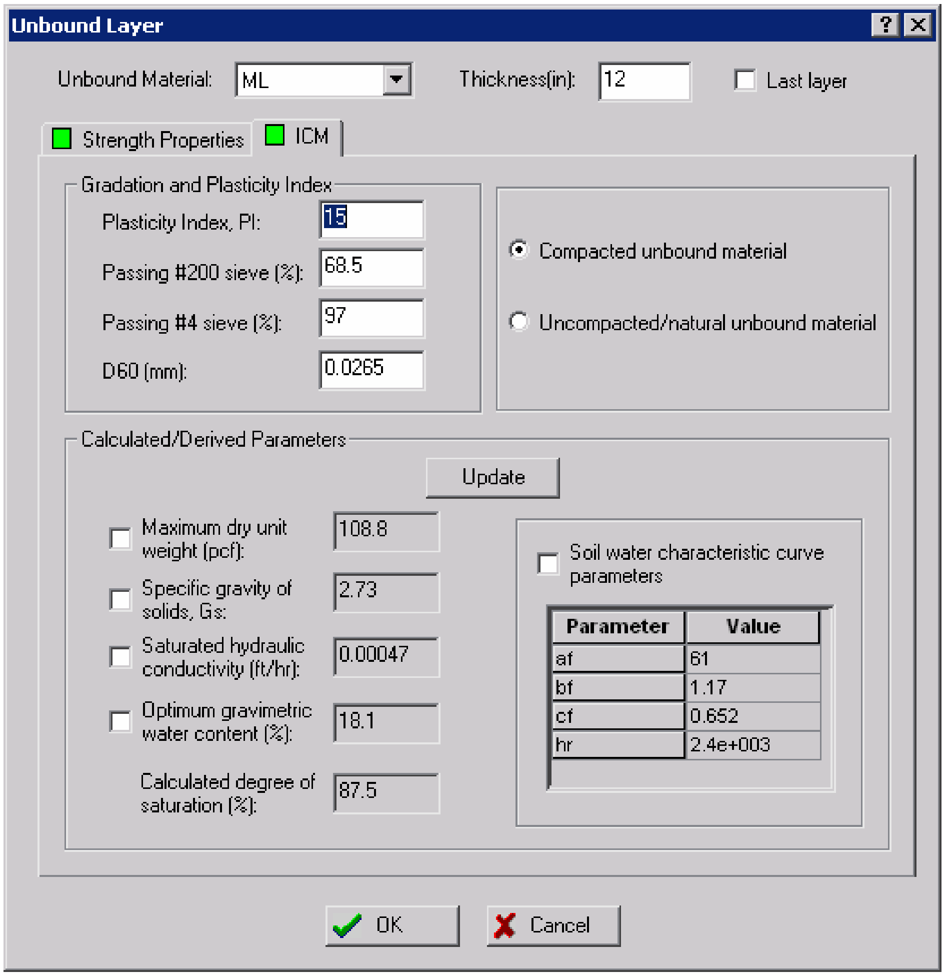


Figure D. 86. *Subgrade (Unbound) layer* screen – *ICM* property page.

D.3.5.3.4 *Layer 4 – ML*

The fourth layer in this trial design is the natural subgrade classified as ML under the unified classification system. Repeat all inputs made for layer 3. However, on the ICM property page, click on the radio button corresponding to *Uncompacted/natural unbound material* as shown in Figure D. 87

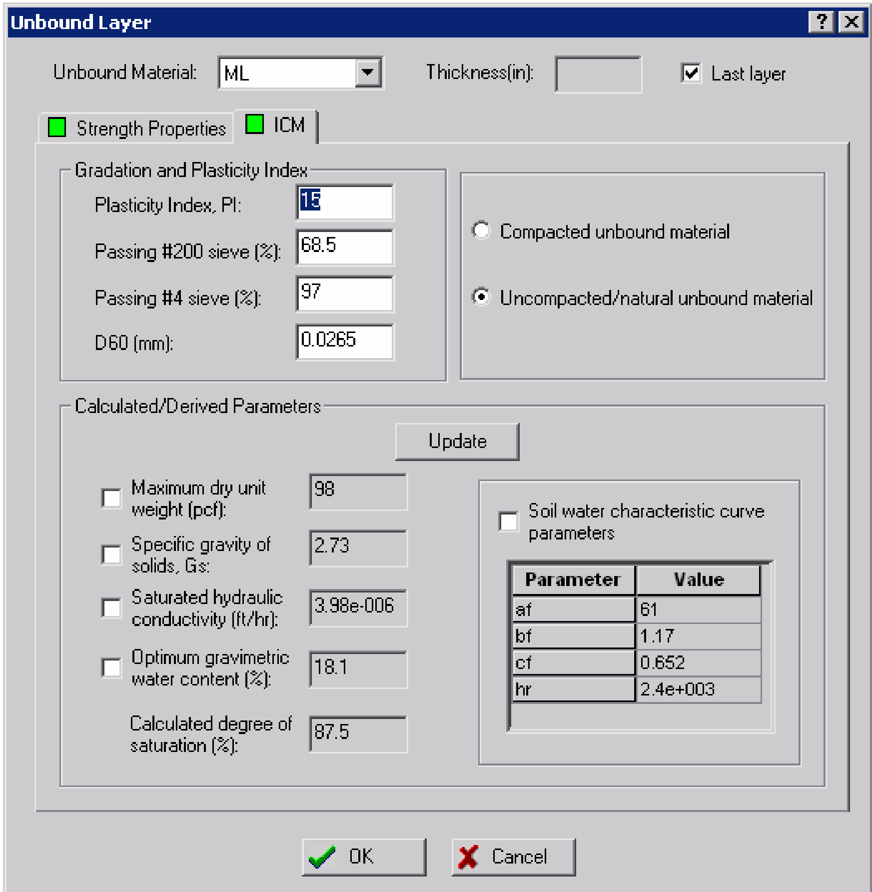


Figure D. 87. *Unbound layer* screen for natural subgrade layer.

Click on *Update* and view the ICM calculated parameters. Next, click *Ok* and return to the program layout screen shown in Figure D. 88. Note that in Figure D. 88, the icons adjacent to all inputs – traffic, climate, and structure – are green indicating that all these inputs are complete.

D.3.6 Run Analysis

After all design inputs are provided, the Design Guide software has to begin the analysis process to predict the performance of the trial design over the design life of the pavement. Click on *Run Analysis*. The program runs the Traffic, Climate, Modulus, Punchout CRCP modules and reports the analysis status on the upper right hand corner of the screen.

At the end of the analysis, the program creates a summary file and other output files in the project directory, C:\DG2002\Projects\CRCP Example. The summary file is in a MS Excel format and is named "*CRCPExample.xls*." The summary file contains an input summary sheet, an distress summary sheet with predicted parameters in a table format, and the predicted punchout, IRI, crack width and LTE in a graphical format. Note that the crack spacing is also printed on the punchout prediction plot.

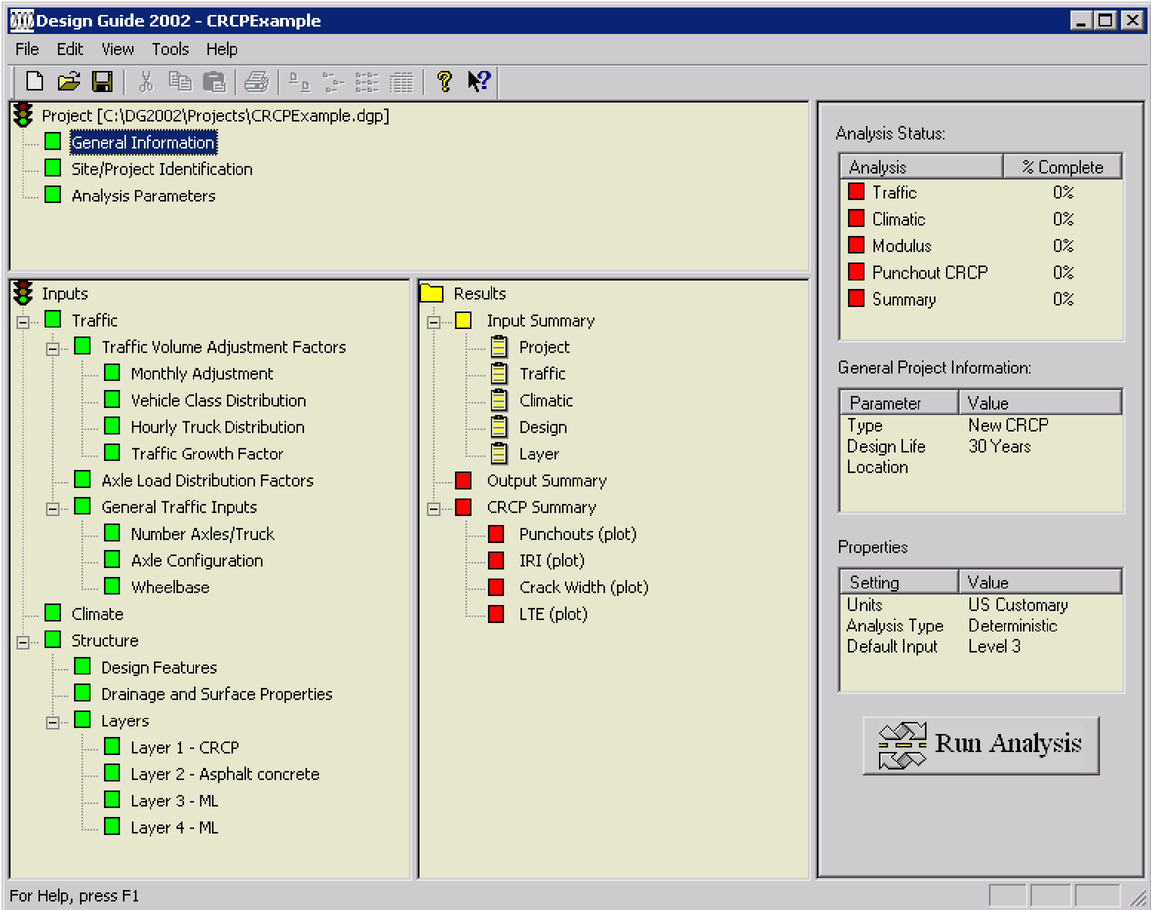


Figure D. 88. Program layout screen after completing all inputs.

The distress summary sheet in the output file provides an overall summary of the CRCP design for the project including critical material properties, traffic, and distress data. Detailed data for each distress type is provided on separate sheets. The distress summary sheet indicates that this pavement carried nearly 21 million heavy trucks over the design period and this provides an overall idea of the traffic loading on the pavement.

For the given trial design, the number of punchouts over the design life as predicted by Design Guide software at the selected reliability level of 95 percent is shown in Figure D. 89. The predicted IRI is shown in Figure D. 90. From these two figures it is clear that the trial design satisfies the smoothness criteria but fails to satisfy the punchout criteria specified.

D.3.7 Modify Trial Design

The user has to now accordingly modify the trial design so that the performance criteria are met. The user has to run several different cases to select the optimum from the feasible design options developed. Possible modifications to this trial design are:

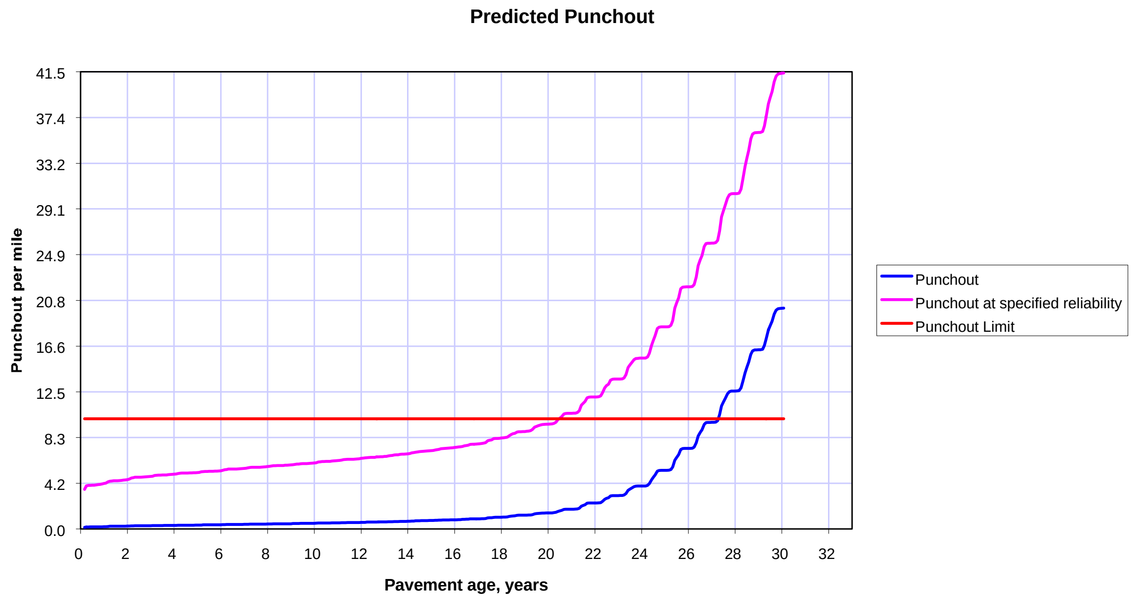


Figure D. 89. Predicted punchout for the trial design.

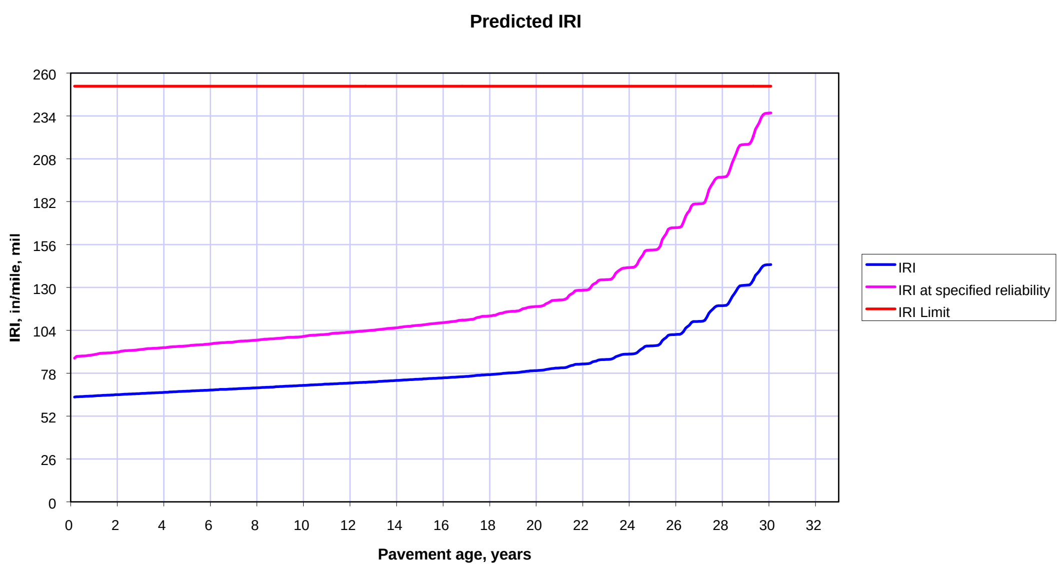


Figure D. 90. Predicted IRI for the trial design.

a) Increase the slab thickness
b) Increase the steel content
c) Increase steel content and decease thickness
d) Increase thickness and decrease steel content

The predicted performance of the pavement at 95 percent reliability level for various thickness and steel content parameters are summarized in Figure D. 91, Figure D. 92, and Figure D. 93.

The feasible design options are clearly the 10 and 11 inch pavement sections with 0.6 or 0.7 percent steel. The optimum choice is the 10 inch section with 0.6 percent steel which meets the design criteria at 95 % reliability level.

Note that several input parameters used in the design can affect the predicted performance. Although the above design example for CRCP suggests altering the thickness and/or steel content, other parameters that can be modified are strength of the concrete mix design, the choice of the base layer, thickness of the base layer, shoulder type etc. Refer to Appendix LL of the Guide for further illustration of the effects of design parameters in the prediction of punchouts for pavements in different climatic zones.

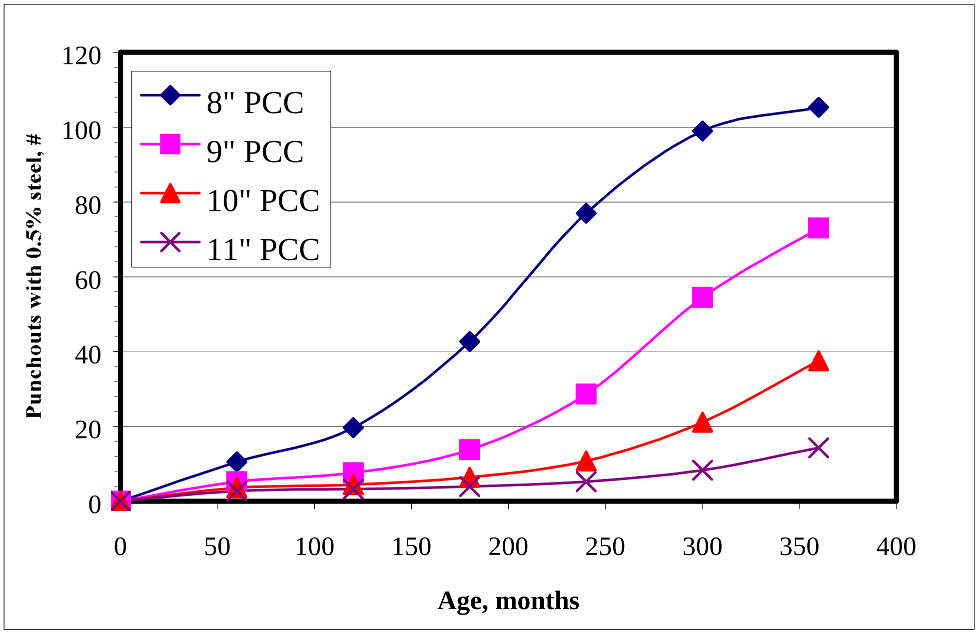


Figure D. 91. Predicted performance at 95 % reliability with 0.5 % steel content.

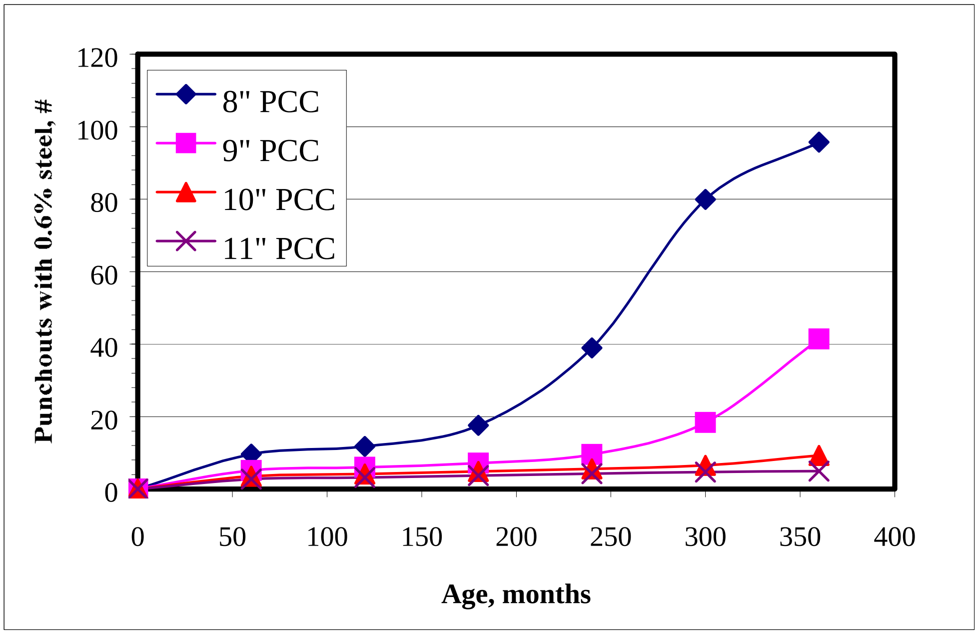


Figure D. 92. Predicted performance at 95 % reliability with 0.6 % steel content.

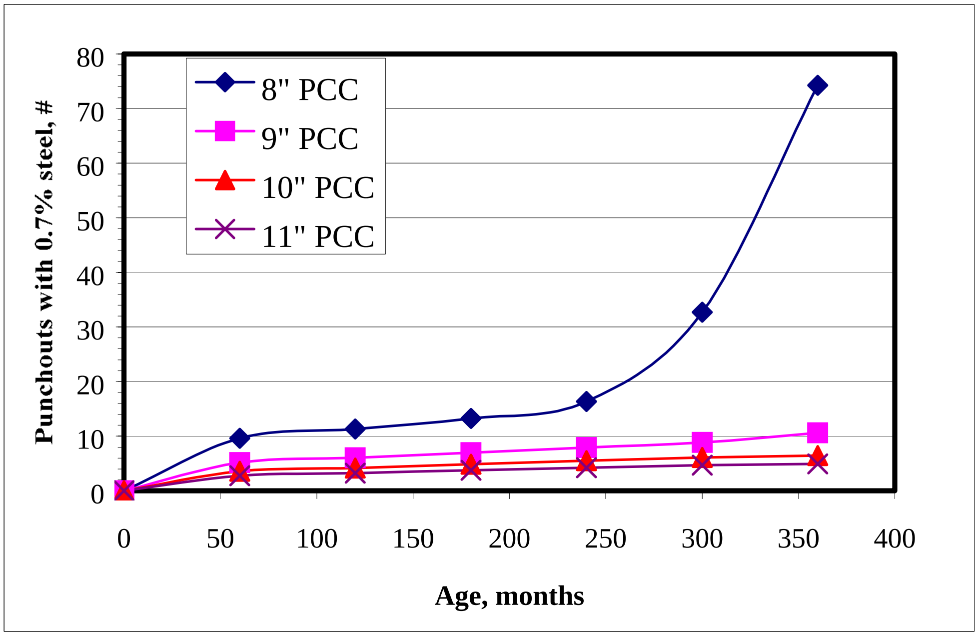


Figure D. 93. Predicted performance at 95 % reliability with 0.7 % steel content.

D.4 JPCP RESTORATION AND UNBONDED JPCP OVERLAY REHABILITATION DESIGN EXAMPLE

This section of the appendix consists of two design examples:

a) JPCP restoration
b) Unbonded JPCP overlay on existing JPCP

The two design examples presented in this section are based on a general problem statement. The two design examples listed above are then used to design an appropriate rehabilitation solution. Although not presented as part of this appendix, the design examples developed should be used in Life-Cycle Costs Analysis (LCCA) to determine the most cost effective design for the given problem statement.

It is expected that prior to performing these examples, the user is familiar with the use of the design software for the design of new JPCP sections. The problem statement for these rehabilitation options covers all information required for making design inputs to the software. Unlike the design examples for new rigid pavements in Section D.2 and D.3 of this appendix, this example does not contain screen shots for all design inputs. It is expected that with the experience of performing a new pavement design, the user will be able to make all inputs for the traffic, climate and structural inputs for the existing pavements. However, appropriate screen shots of the design software that are different from the new design or those that are typical to restoration or rehabilitation design are provided to guide the user with the design procedure. Users are urged to refer to Section D.2 and D.3 where necessary.

D.4.1 Problem Statement for Rehabilitation with JPCP Design

Summarized in Tables D.4.1 are the climate, material properties, structure, and design features of existing JPCP. The information presented was obtained from a comprehensive evaluation of the JPCP using procedures presented in PART 2, Chapter 5 of this Guide. The JPCP was constructed and opened to traffic in July 1971.

Using the data presented in Table D.4.1 as the basis, the following rehabilitation alternatives are considered:

1. Restoration of the existing JPCP including diamond grinding.
2. Unbonded JPCP overlay over the existing JPCP.

Design Life

The expected construction date of the rehabilitation alternative is August 2001 and the rehabilitated pavement must be opened to traffic in September, 2001. Assume 15 years for JPCP restoration (alternative 1), and 25 years for unbonded JPCP overlay over existing JPCP (alternative 2).

Table D.4.1. Existing JPCP climate, material properties, and design features data.

Category	Variable	Value
Climate	Latitude (degrees)	33.12
	Longitude (degrees)	-95.75
	Elevation (ft)	523
	Depth of water table (ft)	10
Design Features—Joint Design	Permanent curl/warp effective temperature difference (°F)	-10
	Joint spacing (ft)	15
	Sealant type	Liquid
	Dowel diameter (in)	No dowels
	Dowel bar spacing (in)	No dowels
Design Features—Edge Support	Tied PCC shoulder	None
	Widened lane	None
	Long-term LTE(percent)	10
	Slab width(ft)	12
Drainage Parameter	Infiltration	Moderate (50 percent)
	Drainage path length (ft)	12
	Pavement cross slope (percent)	2
Base Properties—General	Base type	Cement treated
	Erodibility index	Very Erosion Resistant (2)
	Base/slab friction coefficient	0.65
	PCC-Base Interface	Unbonded
	Loss of bond age (months)	0
	Surface shortwave absorptivity	0.85

Table D.4.1. Existing JPCP climate, material properties, and design features data, continued.

Layer Number	Variable	Value
Layer 1	PCC type	JPCP (existing)
	Layer thickness (in)	10
	Unit weight (pcf)	150
	Poisson's ratio	0.2
	Coefficient of thermal expansion (per F° x 10^{-6})	6
	Thermal conductivity (BTU/hr-ft-F°)	1.25
	Heat capacity (BTU/lb-F°)	0.28
	Cement type	Type I
	Cement content (lb/yd^3)	600
	Water/cement ratio	0.42
	Aggregate type	Limestone
	PCC set temperature (°F)	n/a
	Ultimate shrinkage at 40 percent microstrain)	n/a
	Reversible shrinkage (percent of ultimate shrinkage)	50
	Time to develop 50 percent of ultimate shrinkage (days)	35
	Curing method	Curing compound
	Compressive strength (existing) psi	5000
	Elastic modulus, psi	4,030,000
	Flexural strength MR psi	671
	Tensile strength, psi	520
Layer 2	Material type	Soil Cement
	Layer thickness (in)	6
	Unit weight (pcf)	150
	Poisson's ratio	0.2
	Resilient modulus (psi)	250,000
	Thermal conductivity (BTU/hr-ft-F°)	1.25
	Heat capacity (BTU/lb-F°)	0.28
Layer 3	Material type	A-1-b
	Thickness, in	12
	Poisson's ratio	0.35
	Coefficient of lateral pressure, Ko	0.5
	Modulus, psi	10000
	Plasticity Index, PI	1
	Passing No. 200 sieve, percent	10
	Passing No. 4 sieve, percent	80
	D60, mm	2
	Dry thermal conductivity (BTU/hr-ft-F°)	0.23
	Dry heat capacity (BTU/lb-F°)	0.17

Table D.4.1. Existing JPCP climate, material properties, and design features data, continued.

Layer Number	Variable	Value
Layer 3	Maximum dry unit weight, pcf	122.3 (derived)
	Specific gravity of solids, Gs	2.67 (derived)
	Saturated hydraulic conductivity, ft/hr	37 (derived)
	Optimum gravimetric water content, percent	11.2 (derived)
	Calculated degree of saturation, percent	82.8 (calculated)
	Soil water characteristic curve parameter, a	11.4
	Soil water characteristic curve parameter, b	1.72
	Soil water characteristic curve parameter, c	0.518
	Soil water characteristic curve parameter, hr	371
Layer 4	Material type	A-6
	Thickness, in	Semi-infinite
	Poisson's ratio	0.35
	Coefficient of lateral pressure, Ko	0.50
	Modulus, psi	17000
	Plasticity Index, PI	12
	Passing No. 200 sieve, percent	60.7
	Passing No. 4 sieve, percent	84
	D60 (mm):	0.075
	Dry thermal conductivity (BTU/hr-ft-F°)	0.23
	Dry heat capacity (BTU/lb-F°)	0.17
	Maximum dry unit weight (pcf)	112 (derived)
	Specific gravity of solids, Gs	2.72 (derived)
	Saturated hydraulic conductivity, ft/hr	7.1181e-006 (derived)
	Optimum gravimetric water content, percent	16.5 (derived)
	Calculated degree of saturation, percent	87 (calculated)
	Soil water characteristic curve parameter, a	43
	Soil water characteristic curve parameter, b	1.22
	Soil water characteristic curve parameter, c	0.629
	Soil water characteristic curve parameter, hr	1600
Existing Distress	Percent slabs with transverse cracks plus previously replaced slabs(%):	5
	Percent of slabs with repairs after restoration (%):	0
Foundation Support	Modulus of subgrade reaction, psi/in	250
	Month modulus of subgrade reaction measured	September

Construction Requirements

Assume an initial IRI of 63 in/mile for the unbonded overlay. For the JPCP restoration alternative, it is assumed that the diamond grinding operation will eliminate faulting resulting in an IRI of less than 63 in/mile.

Analysis Parameters

It is expected that at the end of the design life, the pavement will have no more than 15 percent transverse cracking at 90 percent reliability level and no more than 0.15 inch faulting at a reliability level of 90 percent. In addition, the smoothness should be maintained at an IRI of less than 252 in/mile at a reliability level of 90 percent.

Location

Same as location of existing JPCP presented in Table D.4.1. The pavement was located at an elevation of 523 ft and the depth of the water table is 10 feet at this site.

<u>Traffic</u>

Future traffic estimates for rehabilitation design are as follows:

- Two-way average annual daily truck traffic: 2800
- Number of lanes in design direction: 2
- Percent of trucks in design direction: 55 percent
- Percent of trucks in design lane: 95 percent
- Operational speed: 60 mph
- Traffic growth rate design life: 3 percent
- Traffic growth function: Linear

This pavement is categorized as a principal arterial/interstate highway and therefore must be designed for heavy traffic. The traffic characteristics developed using information from past traffic data collected shows the percentage of AADTT in each vehicle class is closest to the default TTC#1 in the Design Guide software.

For each class of vehicle, the traffic pattern on monthly and daily bases remains the same through out the year. However, the traffic varies over a 24-hour period and is same as the national default based on LTPP data (provided in the Design Guide and the software).

The axle load distribution is identical to the LTPP default distribution for each vehicle class, axle type, load category, and months of the year and hence the number of single, tandem, tridem and quad axles is same as the national defaults provided in the Design Guide software.

Assume that for all vehicle classes and axle wheel types, the left and right wheels are located 18 in from the centerline joint and the slab—shoulder joint, respectively. The traffic wander has a standard deviation of 10 inches from the wheels mean location. The axle configuration is as follows:

- Average axle width (edge-to-edge outside dimensions, ft): 8.5
- Dual tire spacing (in): 12

The single and dual tire pressures are 120 psi. The design lane is 12 feet wide. The average axle spacing for tandem, tridem and quad axles are as follows:

Axle Type	Axle Spacing (in)
Tandem	51.6
Tridem	49.2
Quad	49.2

Drainage and Surface Properties

The geometric design of the highway calls for a cross slope of 2 percent. The drainage path will have a length of 12 feet and the infiltration will depend on the chosen shoulder type. Assume a surface shortwave absorptivity of 0.85.

D.4.2 Trial Design of Rehabilitation Alternative 1—JPCP Restoration

Trial design begins with the performance of specific repair activities to the existing pavement to restore the JPCP's structural capacity and functionality. The repair activities are as follows:

1. Repair all existing slabs either by repairing using full-depth concrete patches or by replacing the affected panels entirely.
2. Diamond grinding of the existing JPCP to eliminate existing faulting and to restore pavement functionality. As stated the initial IRI after diamond grinding should be 63 in/mile.

Based on the repair activities performed the restored JPCP will be evaluated based on the design criteria and then suitably modified till a final design is achieved. Modifications for this example imply the adoption of a new set of repair activities with or without the repair activities included in this first iteration. Note that diamond grinding is assumed to be part of the set of repair activities adopted. The design process is integrated into the Design Guide software program and the procedure is as follows:

4.2.1 Create a New project

Create a rehabilitation design project in the Design Guide program

Open the Design Guide program from the *Programs* menu of the operating system (windows 98, 2000, XP, NT). Next open a new file and assign a name to the project, "*JPCP_Restored*" as shown in Figure D.94. Next, select the folder to store the design files as "*C:\DG2002\Projects*". Select US Customary units as the measurement system by clicking the radio button adjacent to it. Click "*OK*" and the program opens the main layout screen of the design project.

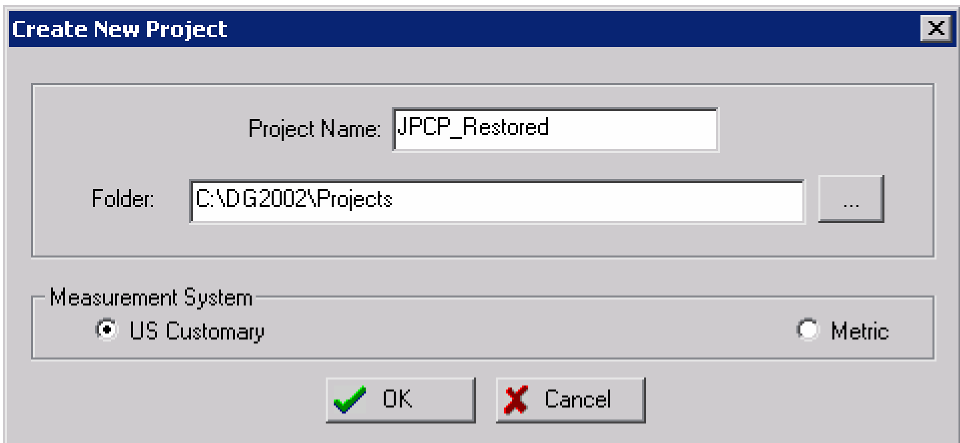


Figure D.94. Create a New Project File from the Main Program.

D.4.2.2 Enter General Inputs

On the main project screen click on the *General Information* input to open the *General Information* screen. Inputs on General Information Screen as shown in Figure D.95. Click *OK* and return to the program layout screen

D.4.2.3 Enter inputs on the Site/Project Identification screen

Click on *Site/Project Identification* to open the *Site/Project Identification* screen. The inputs procedure for this design is same as for new design.

D.4.2.4 Enter inputs on the *Analysis Parameters* screen

Enter the analysis criteria for the desired JPCP section after restoration as shown in Figure D.96.

On the program layout screen, note that there is an additional category of inputs for a rehabilitation project – Rehabilitation. This screen allows the user to input the condition of the existing pavement.

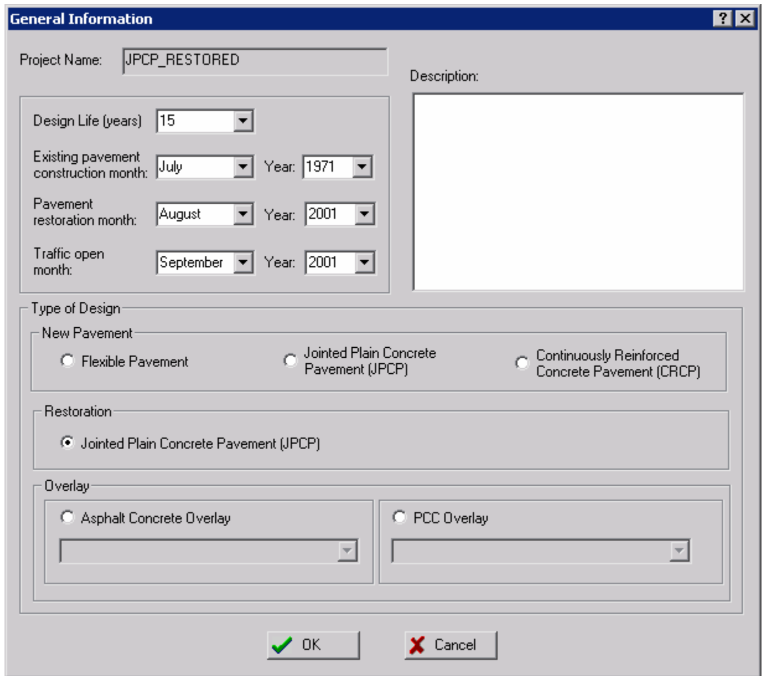


Figure D.95. *General Information* screen.

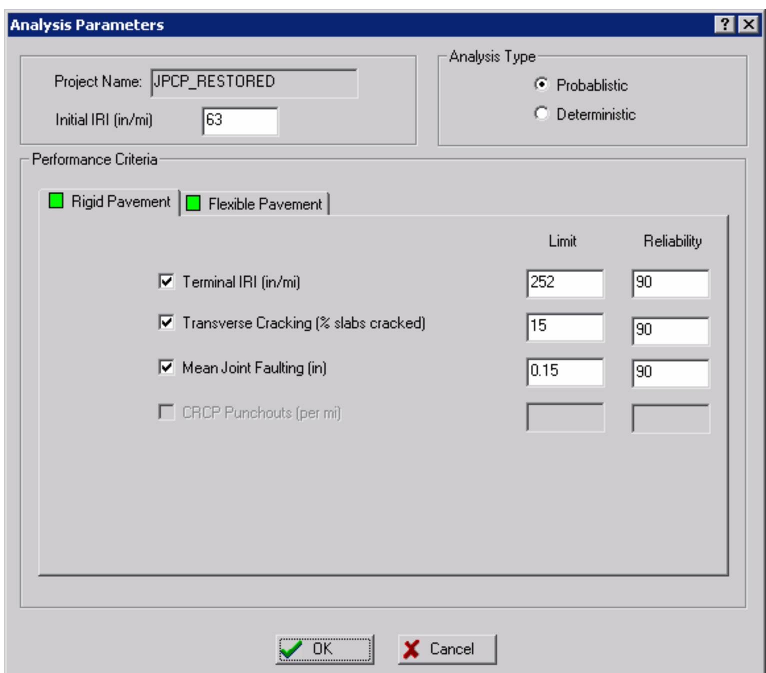


Figure D.96. *Analysis Parameters* screen for JPCP.

D.4.2.5 Traffic Inputs

Traffic inputs are the same as that of new design. Follow the step-by-step procedure provided for new design. Note that actual inputs required for this design is presented in Table D.4.1 and the problem statement.

D.4.2.6 Climate Inputs

Climate inputs are the same as that of new design. Follow the step-by-step procedure provided for new design. Note that actual inputs required for this design is presented in Table D.4.1 and the problem statement.

D.4.2.7 Structural Inputs

The structural inputs for a JPCP restoration project are similar to the structural inputs for a new design and essentially fall under the following three categories:

- Design features.
- Drainage and surface properties.
- Layer.

The user at this stage needs to choose design features, drainage and surface properties, and layer material properties and thickness that can be evaluated for its performance. Note that for this example (JPCP restoration) the pavement structure, material properties, and design features chosen must be as built or should reflect insitu conditions. The inputs may be varied, however, to reflect changes made as part of repairs and treatments (e.g., addition of retrofit dowels). The existing as-built design features, drainage and surface properties, and layer material properties and thickness are presented in Table D.4.1. For this example repairs consisted of slab replacement and full-depth patching and hence the existing design features and material properties will not be altered.

Layers - Defining Pavement Structure

In this example, the users will be guided to add the pavement layers first instead of making inputs on the JPCP Features screen. Note that, as explained in Section D.2, the program does not require a specific order to be followed in making inputs. Figure D. 97 shows the structure of the existing pavement. The pavement structure consisted of 4 layers (including the subgrade) as presented in Table D.4.1. Information required for this screen may be obtained for various source including field-testing, laboratory analysis, and agency records as discussed in PART 2, Chapter 5.

Input *Layer 1- JPCP (Existing)* Properties

Next, after defining the pavement structure input PCC material properties required for the existing JPCP layer. Material properties required are presented in Table D.4.1.

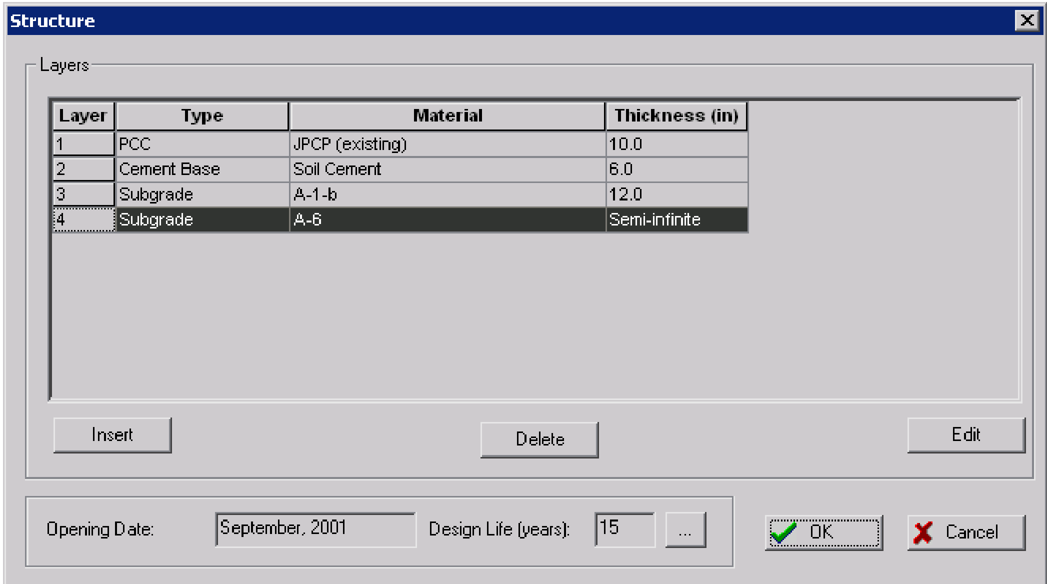


Figure D. 97. Adding existing layers to form the pavement structure in JPCP Restoration.

Inputs for *PCC-Thermal and Strength* property pages are similar to those made for the new design presented in Section D.2 of this appendix. The material strength data available is from the existing condition. Enter level 1 PCC strength data on the *PCC-Strength* property page, as shown in Figure D. 98.

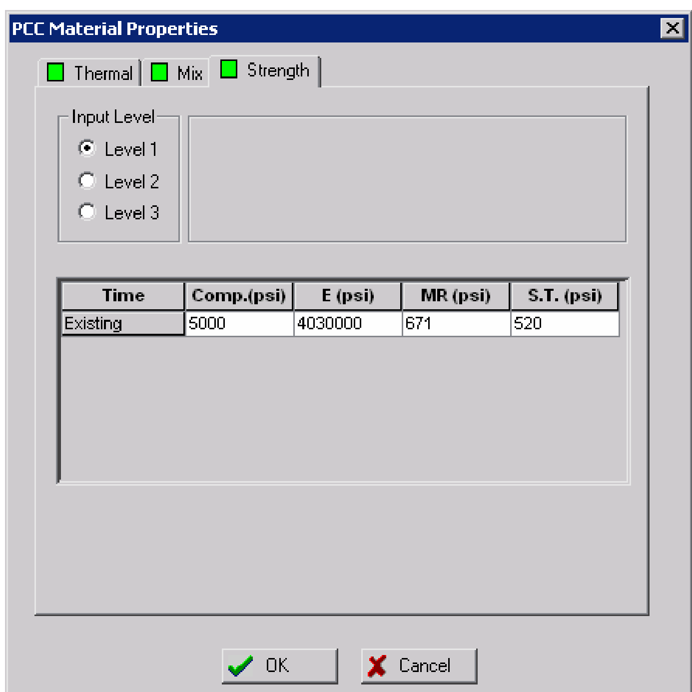


Figure D. 98. *PCC Materials Properties—Strength* screen.

Input *Layer 2-Soil Cement* Properties

Input Layer 2 (soil cement) material properties provided in Table D.4.1 as shown in figure D. 99.

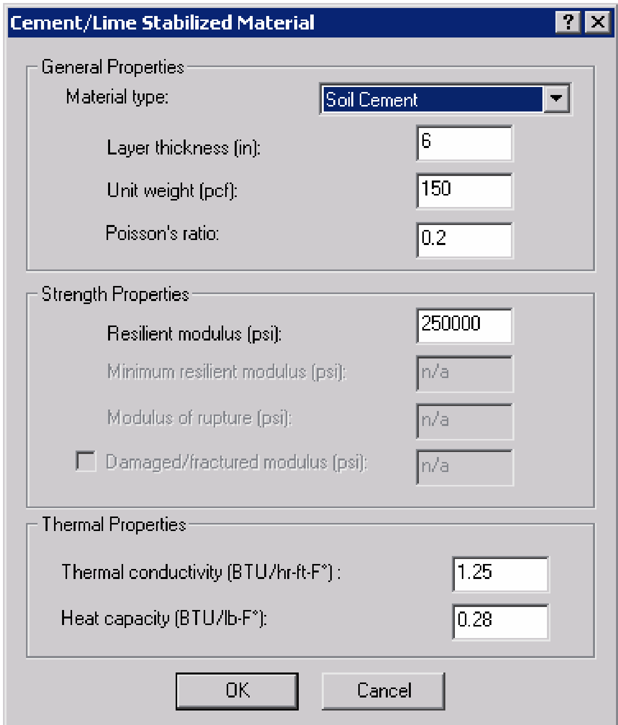


Figure D. 99. *Cement/Lime Stabilized Material* screen.

Input *Layer 3-A-1-b* Properties

Unbound layer inputs for the subbase A-1-b layer are the same as that for new design. Follow the step-by-step procedure provided for new JPCP design in Section D.2 of this appendix. Note that actual inputs required for this design are presented in Table D.4.1.

Input *Layer 4-A-6* Properties

Unbound layer inputs for the subgrade A-6 layer are the same as that for new design. Follow the step-by-step procedure provided for new JPCP design in Section D.2 of this appendix. Note that actual inputs required for this design are presented in Table D.4.1.

Design Features

Design features information required for JPCP design are shown in Figure D. 100. Data inputs for this screen are obtained through the evaluation of the existing JPCP as described in PART 2, Chapter 5. Note that the design features selected must reflect changes to repair treatments (e.g., retrofit dowels) applied as part of restoration.

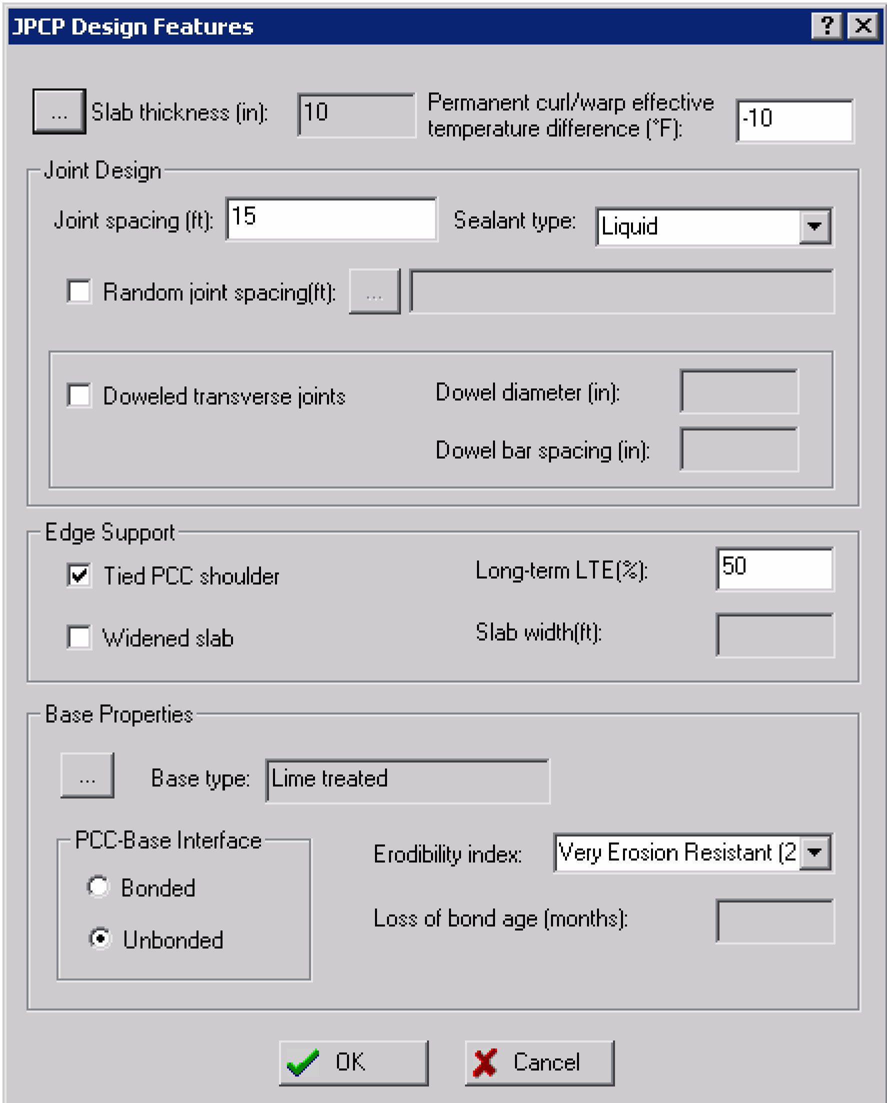


Figure D. 100. *JPCP Design Features*—screen.

<u>*Drainage and Surface Properties*</u>

Enter *Drainage and Surface Properties* inputs from data provided in Table D.4.1.

<u>*D.4.2.8 Rehabilitation*</u>

Click on *Rehabilitation* on the program layout screen to enter inputs regarding existing distresses in the pavement. Inputs for the Rehabilitation screen are shown in Figure D. 101.

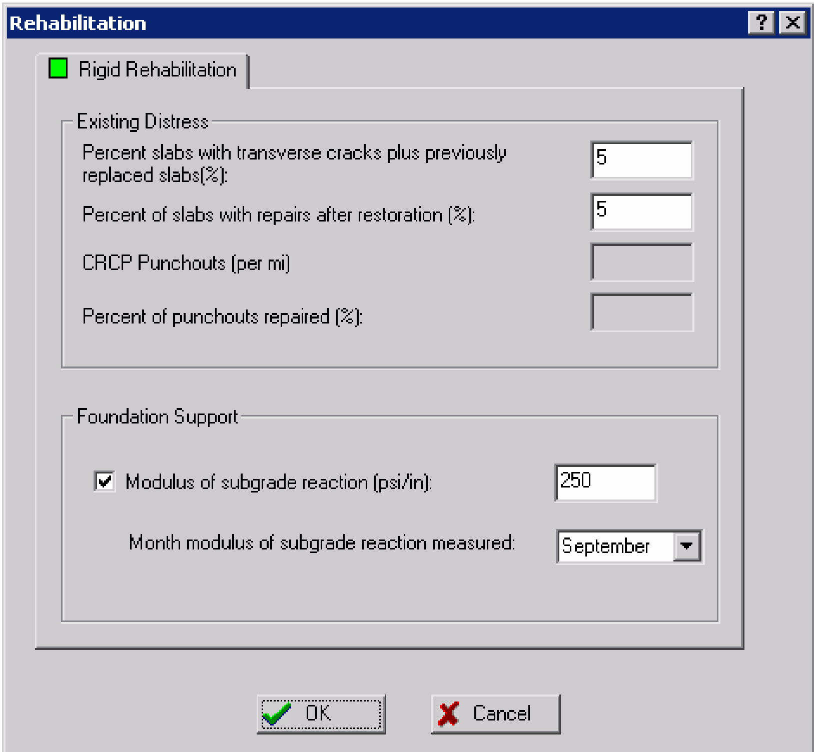


Figure D. 101. *Rehabilitation* screen.

Click *Ok* and return to the program layout screen shown in Figure D. 102. Note that in Figure D. 102, the icons adjacent to all inputs – traffic, climate, and structure – are green indicating that all these inputs are complete.

D.4.2.9 Run Analysis

After all design inputs are provided, the Design Guide software has to begin the analysis process to predict the performance of the trial design over the design life of the pavement. Click on *Run Analysis*. The program runs the Traffic, Climate, Modulus, faulting JPCP, Cracking JPCP modules and reports the analysis status on the upper right hand corner of the screen.

At the end of the analysis, the program creates a summary file and other output files in the project directory, *C:\DG2002\Projects\JPCP_Restored*. The summary file is in a MS Excel format and is named "*JPCP_Restored.xls*" and is similar to the summary file created for new JPCP design. The summary file contains an input summary sheet, distress, faulting, and cracking summary sheets in a table format, and the predicted faulting, LTE, differential energy, cumulative damage, cracking, and IRI in a graphical format.

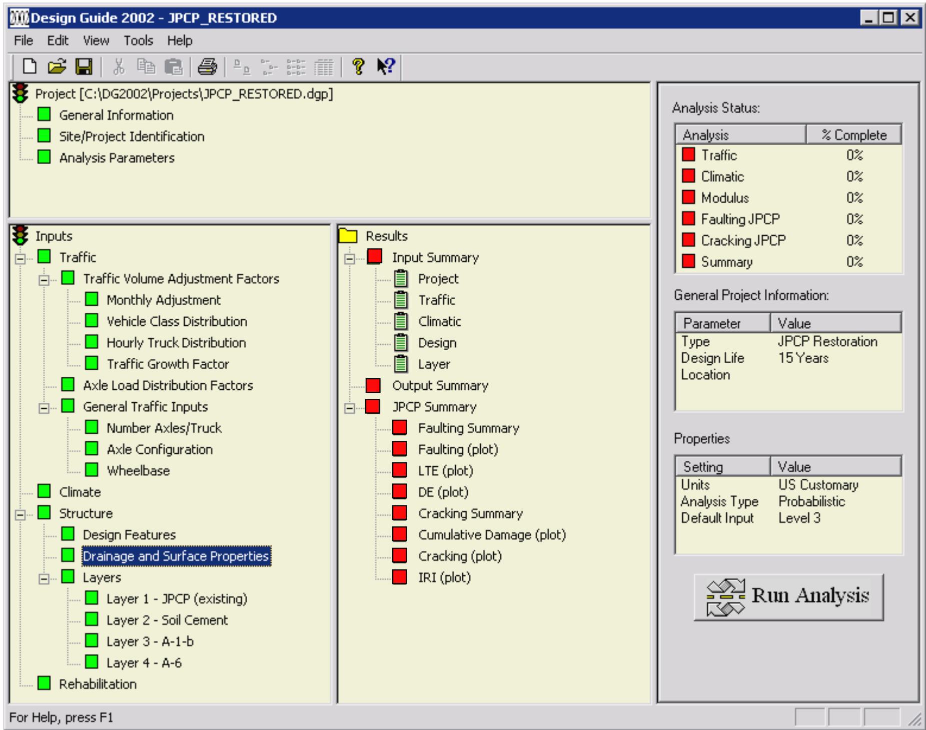


Figure D. 102. Program layout screen after completing all inputs.

For the given trial design, the transverse cracking and faulting over the design life as predicted by Design Guide software at the selected reliability level are shown in Figure D. 103 and in Figure D. 104 respectively. The predicted IRI is shown in Figure D. 105. From these three figures it is clear that the trial design satisfies all three performance criteria - faulting, transverse cracking, and smoothness – at the selected reliability levels.

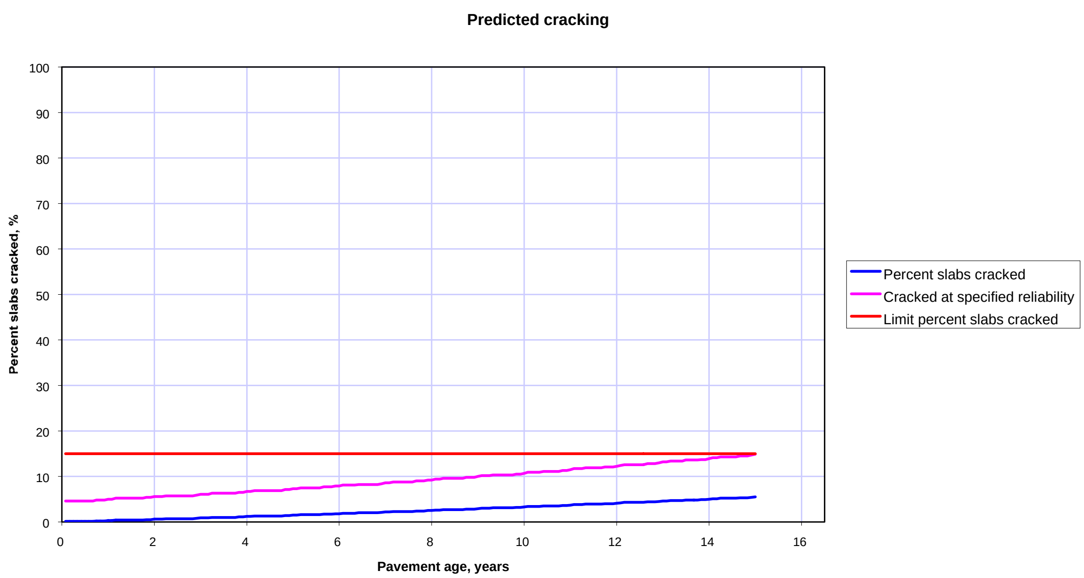


Figure D. 103. Predicted transverse cracking at 90 percent reliability for the trial design.

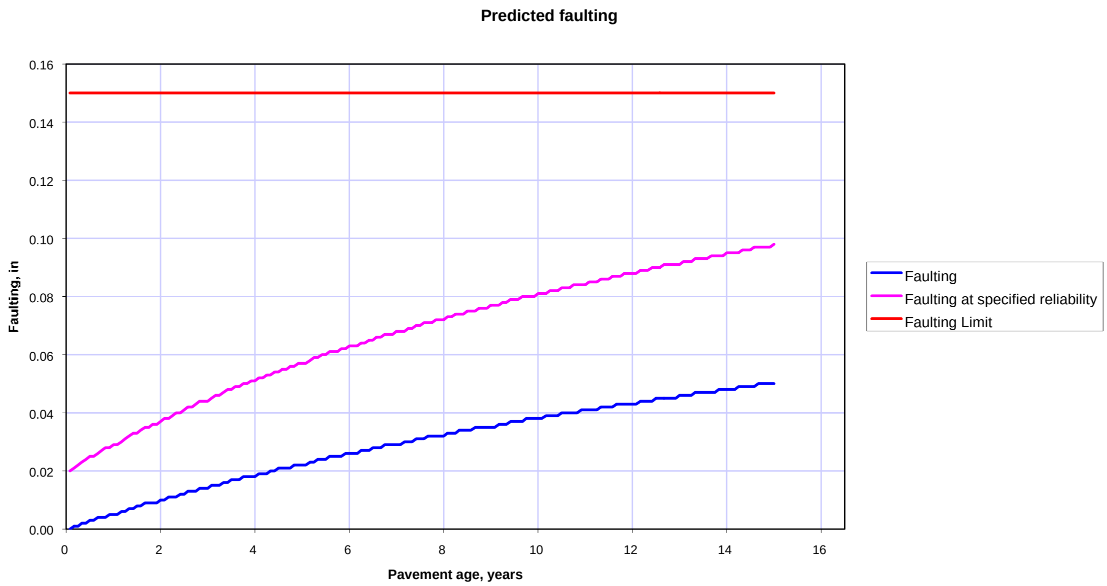


Figure D. 104. Predicted faulting at 90 percent reliability for the trial design.

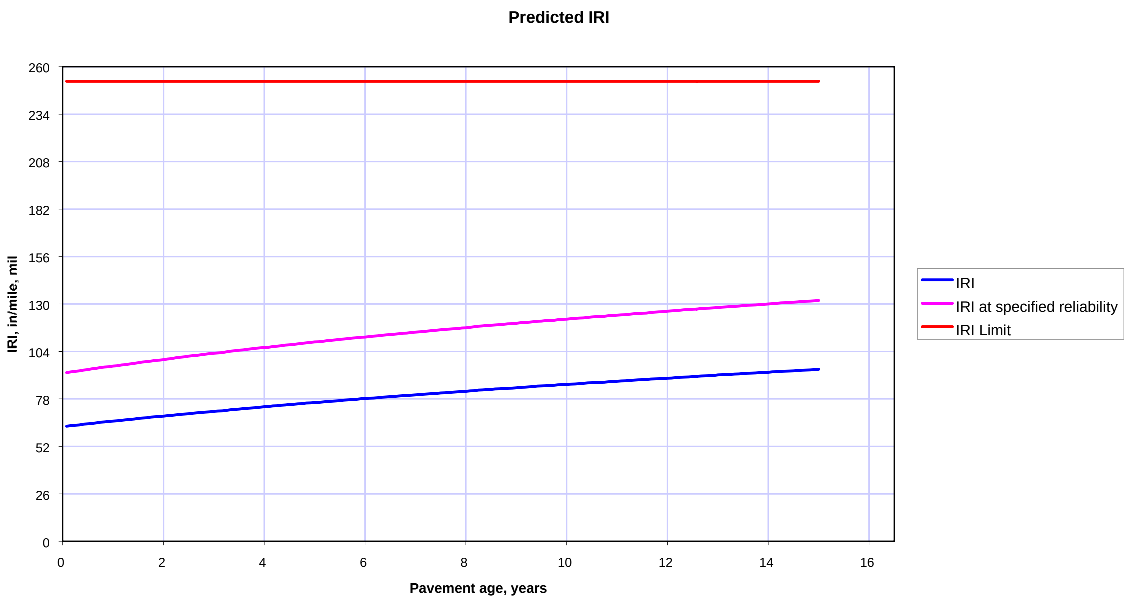


Figure D. 105. Predicted IRI at 90 percent reliability for the trial design.

D.4.3 Trial Design of Rehabilitation Alternative 2—Unbonded JPCP Overlay on Existing Overlay

The design example for the unbonded overlay has a design life of 25 years. The JPCP Restoration alternative, discussed in Section D.5.2, cannot satisfy the required performance criteria expected at the end of the design life. Although the procedure for evaluating this design using JPCP Restoration is not discussed in this section, the user can verify the design by changing the design life of the JPCP Restoration example to 25 years.

The rehabilitation alternative used for this design example is the Unbonded JPCP overlay on the Existing JPCP. The inputs for the existing structure are provided in Table D.4.1

<u>*D.4.3.1 Create a New project*</u>

<u>Create a rehabilitation design project in the Design Guide program</u>

Open the Design Guide program from the *Programs* menu of the operating system (windows 98, 2000, XP, NT). Next open a new file and assign a name to the project, "*JPCP_Unbonded*" as shown in Figure D.106. Next, select the folder to store the design files as "*C:\DG2002\Projects*". Select US Customary units as the measurement system by clicking the radio button adjacent to it. Next, click "*OK*" and the program opens the main layout screen of the design project.

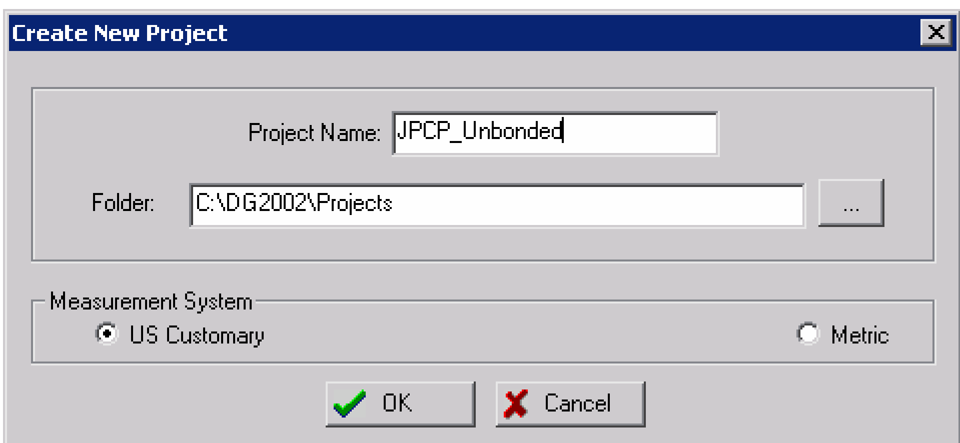


Figure D.106. Create a new project file from the main program.

<u>*D.4.3.2 Enter General Inputs*</u>

On the main project screen click on the *General Information* input to open the *General Information* screen. Enter the design life and information regarding construction and opening dates. Next, click on the radio button corresponding to PCC overlay and choose Unbonded JPCP Over JPCP from the draw down menu as shown in Figure D.107. Click *OK* and return to the program layout screen

D.4.3.3 Enter inputs on the Site/Project Identification screen

Same as for New design.

D.4.3.4 Enter inputs on the Analysis Parameters screen

Enter the analysis criteria for the desired JPCP section after restoration as shown in Figure D.11.

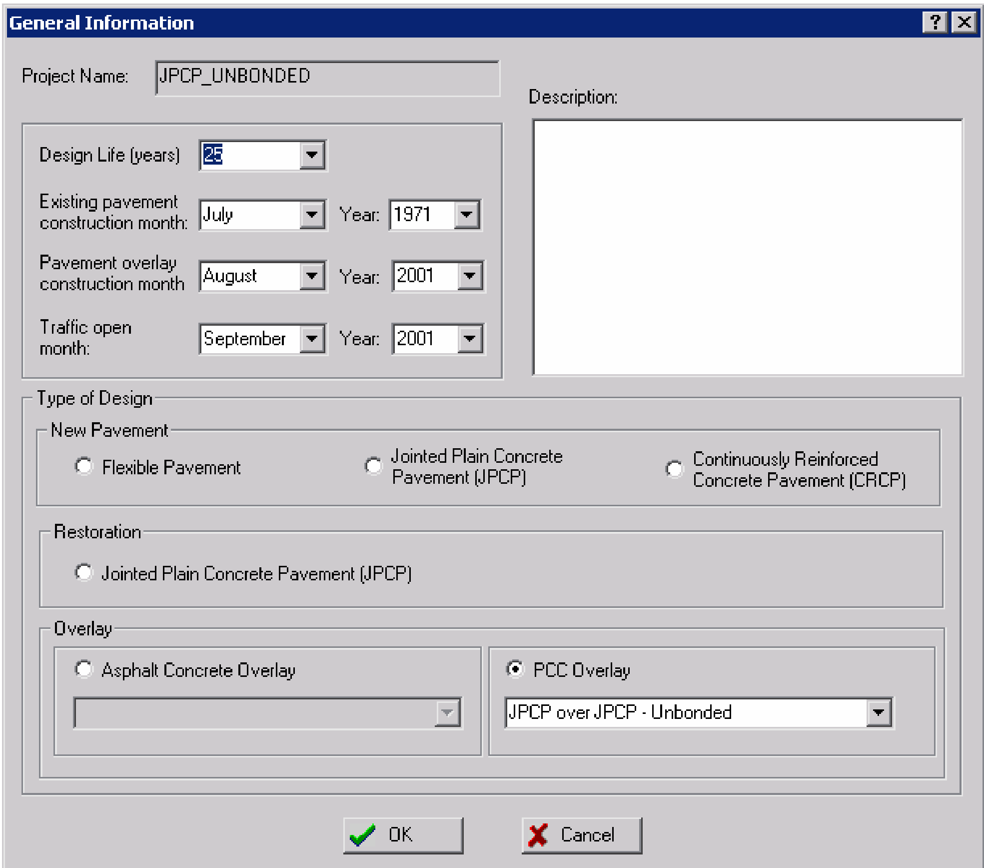


Figure D.107. *General Information* screen.

D.4.3.5 Traffic Inputs

Traffic inputs are the same as that of new design. Follow the step-by-step procedure provided for new design. Note that actual inputs required for this design is presented in Table D.4.1 and the problem statement.

D.4.3.6 Climate Inputs

Climate inputs are the same as that of new design. Follow the step-by-step procedure provided for new design. Note that actual inputs required for this design is presented in Table D.4.1 and the problem statement.

D.4.3.7 Structural Inputs

The structural inputs for this design example are similar to the structural inputs for a new design and a JPCP restoration project. The inputs fall under the three categories:

- Design features.
- Drainage and surface properties.
- Layers.

The user at this stage needs to choose design features, drainage and surface properties, and layer material properties and thickness for the new layers so that the performance of the pavement structure can be evaluated over the design life.

Layers - Defining Pavement Structure

In this example, the users will be guided to add the pavement layers first instead of making inputs on the JPCP Features screen. Note that, when the user makes a choice for the overlay type (JPCP over JPCP) on the *General Information* screen, the program automatically adds a new JPCP layer and an asphalt concrete layer over an existing JPCP layer. Click on *Layers* on the program layout screen and create the pavement structure (new and existing layers) as shown in Figure D. 108.

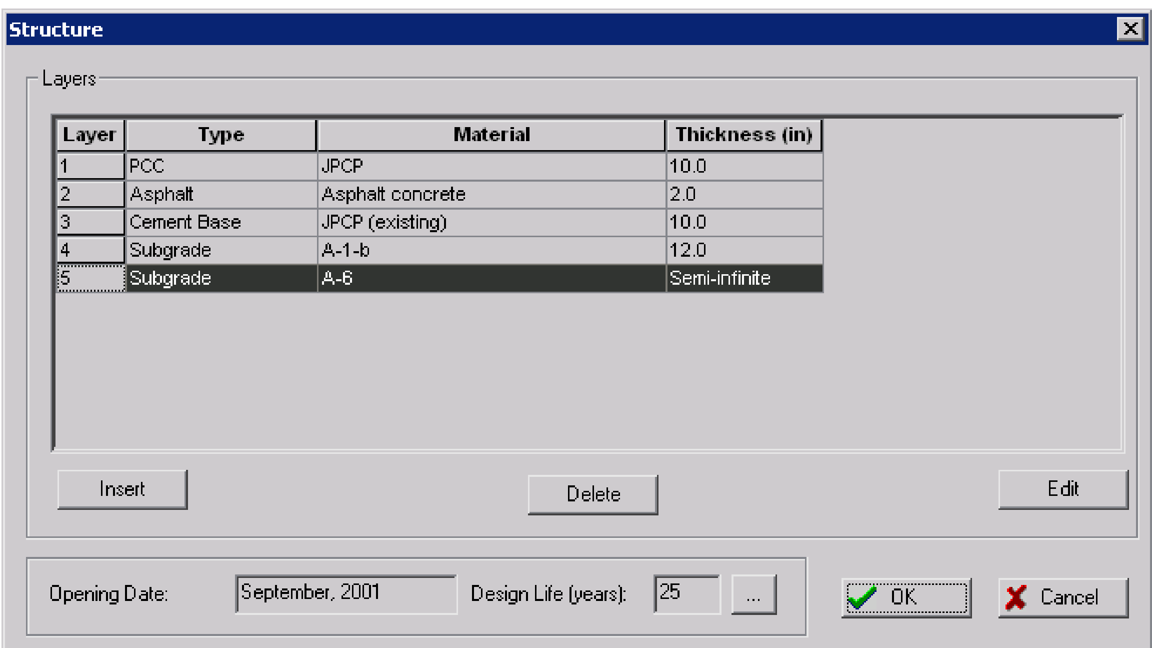


Figure D. 108. Adding New and Existing layers to form the pavement structure for Unbonded JPCP over Existing JPCP.

The suggested trial design for this design example includes the following layers:

- 10-inch JPCP layer (new)
- 2-inch asphalt concrete (new separator layer)
- 10-inch JPCP (existing)
- 12-inch unbound A-1-b layer (existing)
- Semi-infinite A-6 subgrade layer (existing natural subgrade)

The JPCP overlay will have a joint spacing of 15 feet and 1.25 inch diameter dowels spaced at 12 inches.

Input *Layer 1- JPCP* Properties

The inputs for this layer will be representative of the PCC material to be used in the new *JPCP* layer. Figure D. 109, Figure D. 110, and Figure D. 111 show the property pages to enter inputs for PCC *Thermal*, *Mix* and *Strength* properties. Level 3 strength inputs will be used for this example, and the 28-day concrete modulus of rupture is 650 psi.

Input *Layer 2-Asphalt Concrete* Properties

Level 3 inputs are used for the asphalt concrete layer. Figure D. 112, Figure D. 113, and Figure D. 114 show the inputs for asphalt concrete *Mix properties*, *Binder properties, and Asphalt General properties* screens. Note that the procedure for making these inputs are same as that described in the new CRCP design in Section D.3 of this appendix. Note that Superpave binder grading is used in this example instead of a conventional viscosity grading. A PG 64-22 grading binder is used in the AC layer for this example.

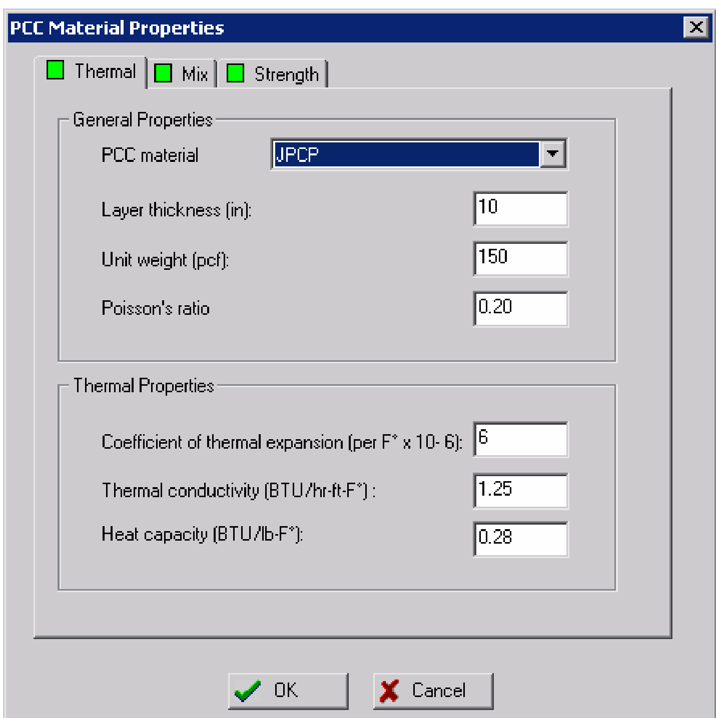


Figure D. 109. *PCC Materials Properties—Thermal* screen.

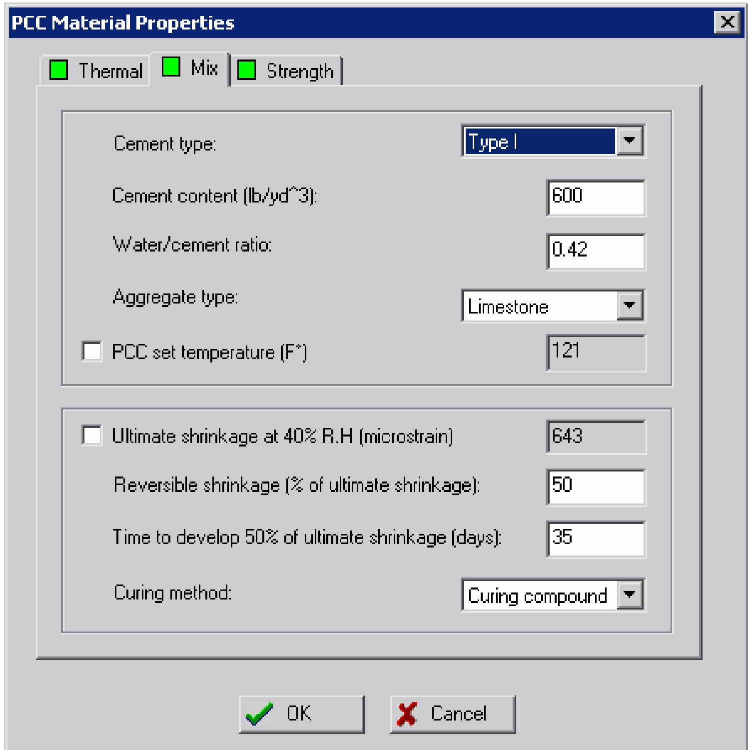


Figure D. 110. *PCC Materials Properties—Mix* screen.

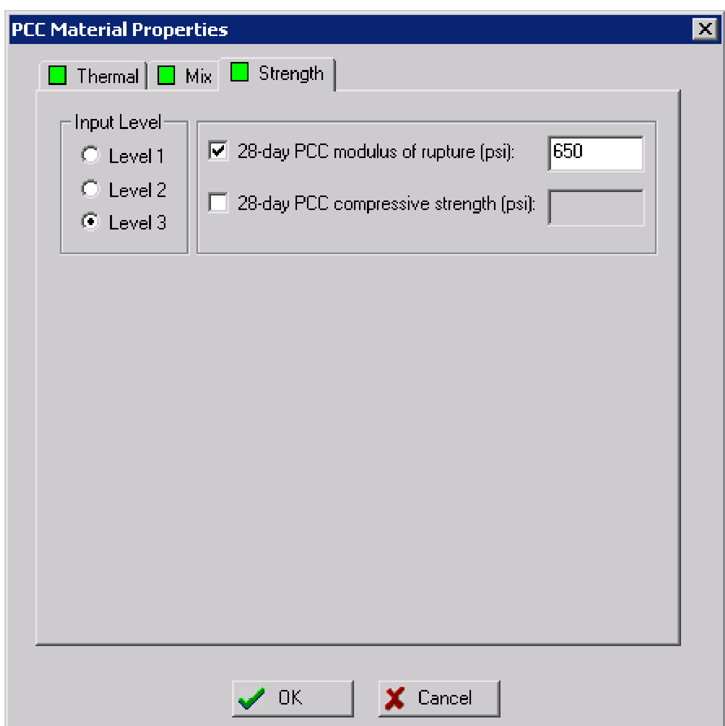


Figure D. 111. *PCC Materials Properties—Strength* screen.

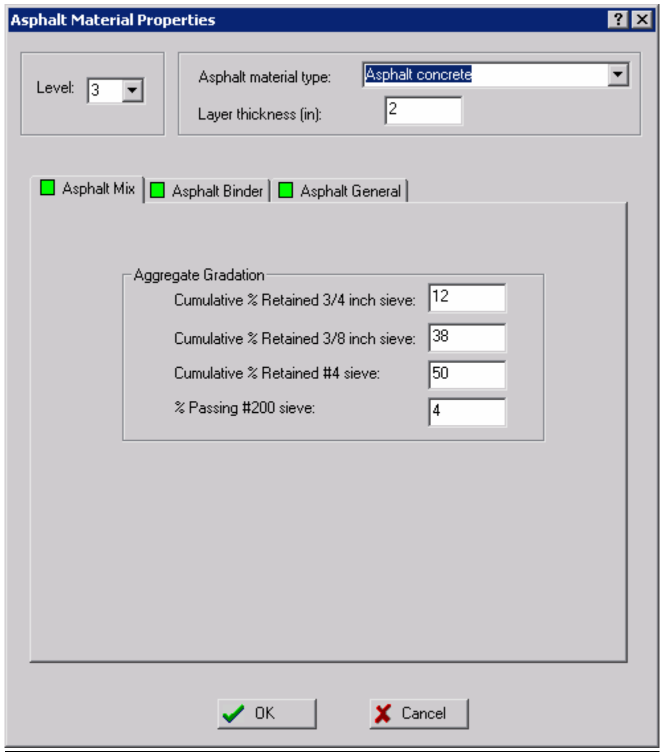


Figure D. 112. *Asphalt Material Properties –Asphalt Mix* screen.

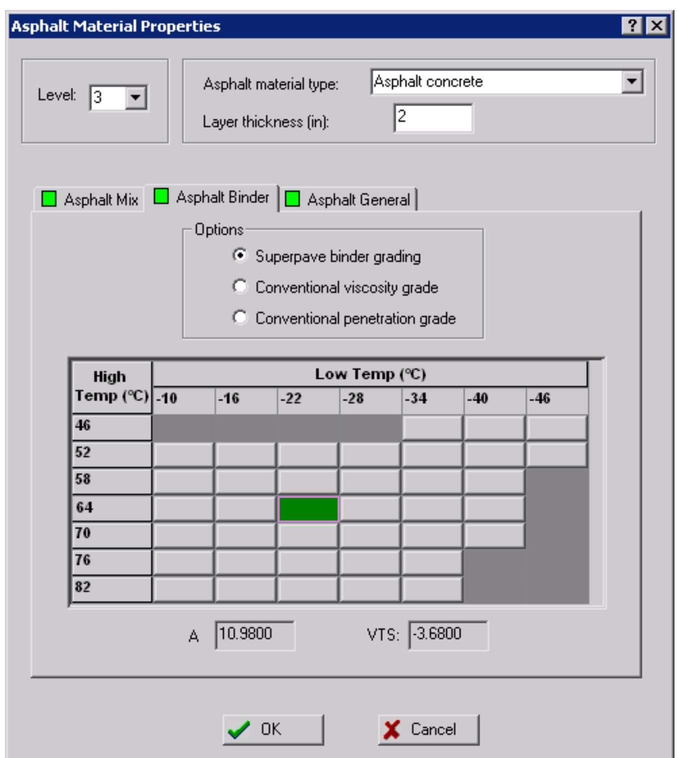


Figure D. 113. *Asphalt Material Properties –Asphalt Binder* screen.

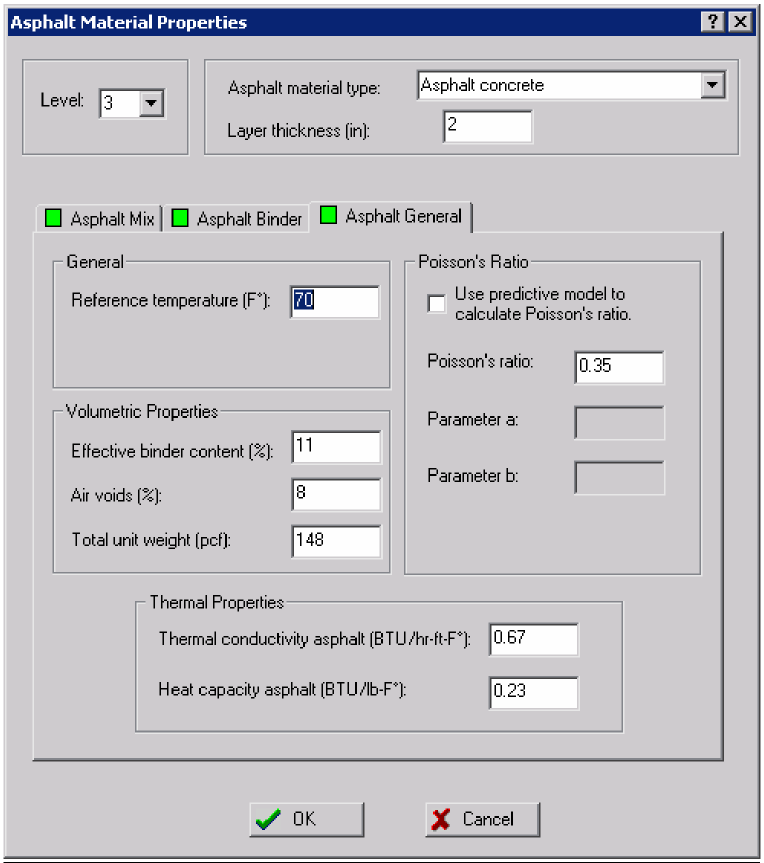


Figure D. 114. *Asphalt Material Properties –Asphalt General* screen.

<u>Input *Layer 3-JPCP (Existing)* Properties</u>

The existing JPCP layer is treated as a stabilized base layer in the design process. The inputs for this layer are shown in Figure D. 115.

<u>Input *Layer 4-A-1-b* Properties</u>

Unbound layer inputs for the subbase A-1-b layer are the same as that for new design. Follow the step-by-step procedure provided for new JPCP design in Section D.2 of this appendix. Note that actual inputs required for this design are presented in Table D.4.1.

<u>Input *Layer 5-A-6* Properties</u>

Unbound layer inputs for the subgrade A-6 layer are the same as that for new design. Follow the step-by-step procedure provided for new JPCP design in Section D.2 of this appendix. Note that actual inputs required for this design are presented in Table D.4.1.

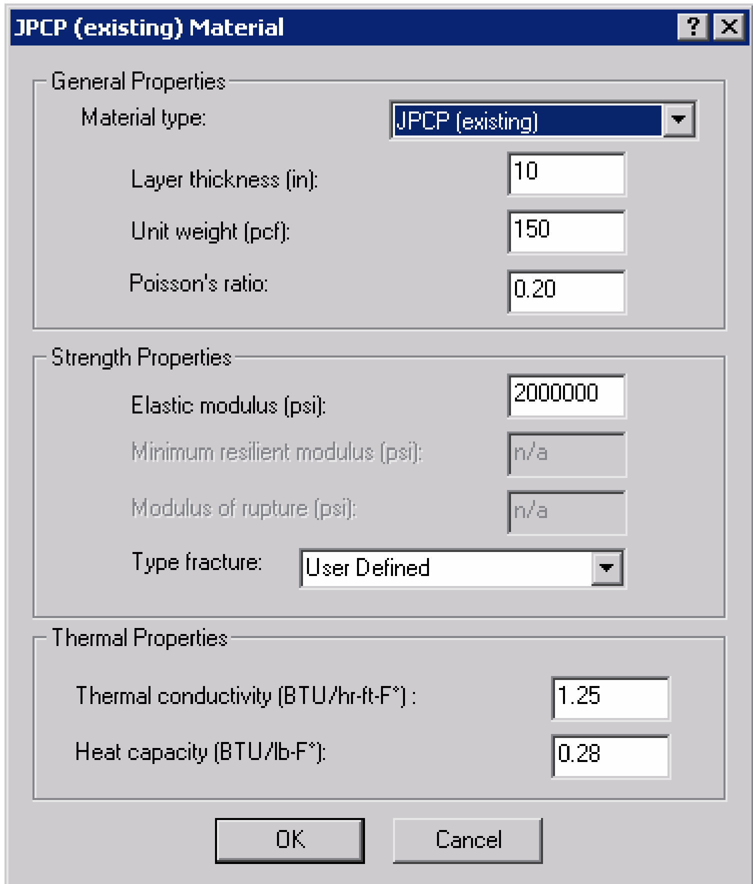


Figure D. 115. *JPCP (Existing) layer Materials* screen.

Design Features

The *Design Features* screen shown in Figure D. 116 will be representative of the features of the new JPCP layer in the design. Enter the selected dowel diameter, spacing and shoulder type. Note that the radio button selecting an unbonded PCC-Base interface is clicked on this screen.

Drainage and Surface Properties

Enter *Drainage and Surface Properties* inputs same as new JPCP design.

D.4.3.8 Rehabilitation

Click on *Rehabilitation* on the program layout screen to enter inputs regarding existing distresses in the pavement. Figure D. 117 shows the inputs for the Rehabilitation screen.

Click *Ok* and return to the program layout screen. Note that this screen now indicates that all inputs are complete.

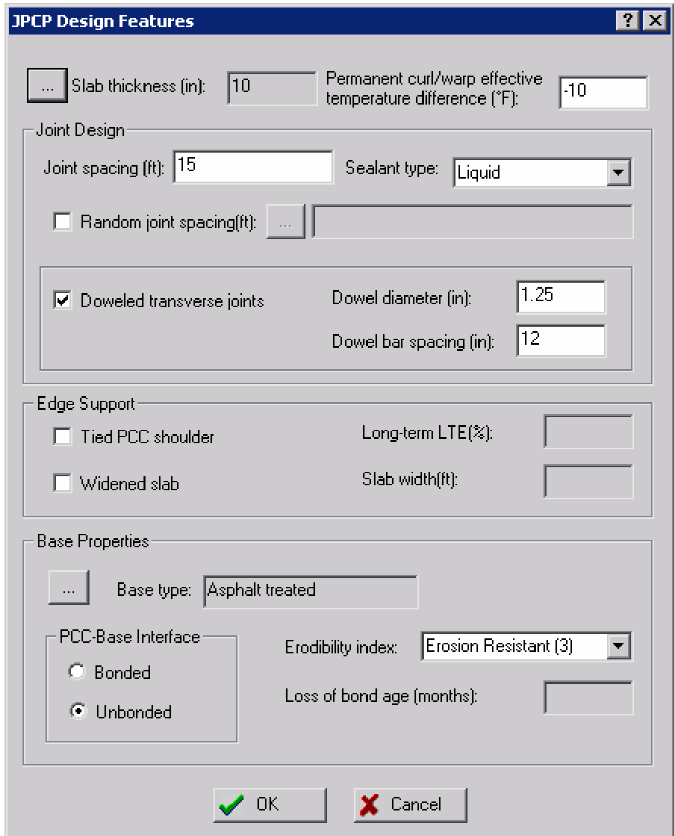


Figure D. 116. *JPCP Design Features*—screen.

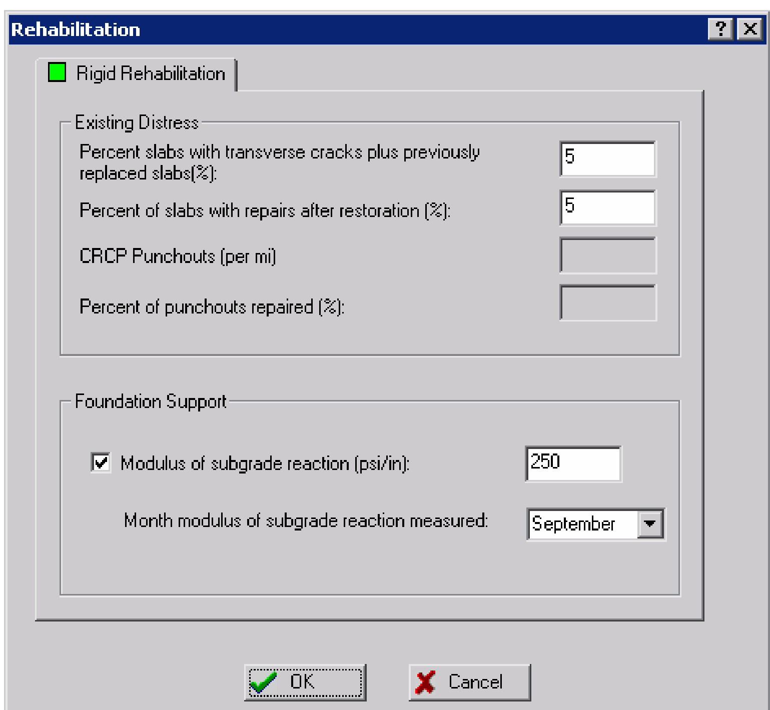


Figure D. 117. *Rehabilitation* screen.

D.4.3.9 Run Analysis

After all design inputs are provided, the Design Guide software has to begin the analysis process to predict the performance of the trial design over the design life of the pavement. Click on *Run Analysis*. The program runs the Traffic, Climate, Modulus, faulting JPCP, Cracking JPCP modules and reports the analysis status on the upper right hand corner of the screen.

At the end of the analysis, the program creates a summary file and other output files in the project directory, *C:\DG2002\Projects\JPCP_Unbonded*. The summary file is in a MS Excel format and is named "*JPCP_Restored.xls*" and is similar to the summary file created for new JPCP design. The summary file contains an input summary sheet, distress, faulting, and cracking summary sheets in a table format, and the predicted faulting, LTE, differential energy, cumulative damage, cracking, and IRI in a graphical format.

For the given trial design, the transverse cracking and faulting over the design life as predicted by Design Guide software at the selected reliability level are shown in Figure D. 118 and in Figure D. 119 respectively. The predicted IRI is shown in Figure D. 120. From these three figures it is clear that the trial design satisfies all three performance criteria - faulting, transverse cracking, and smoothness – at the selected reliability levels.

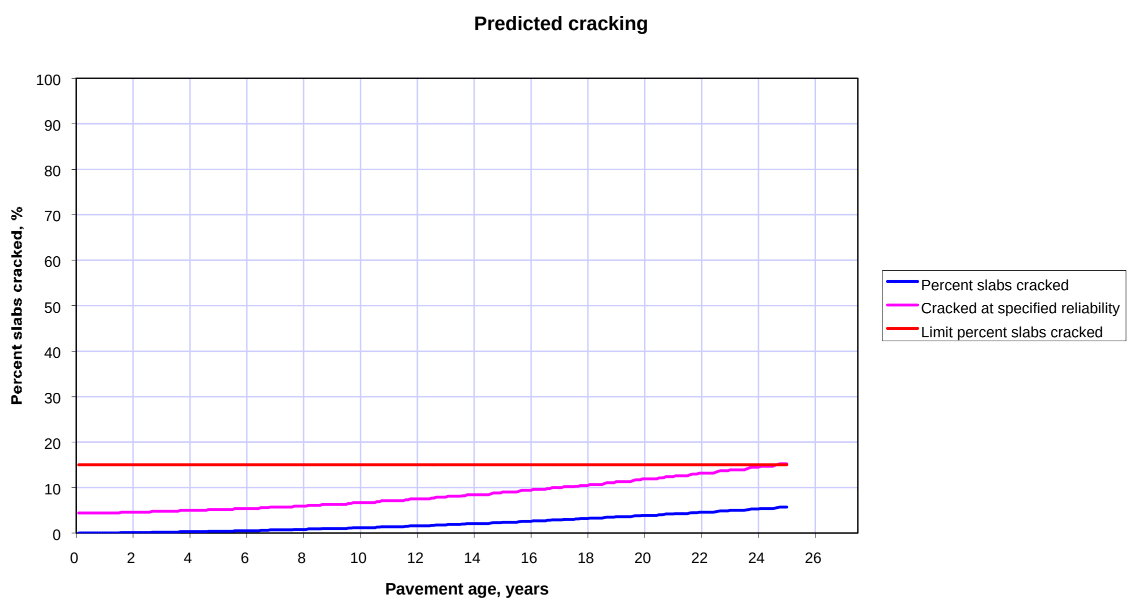


Figure D. 118. Predicted transverse cracking at 90 percent reliability for the trial design.

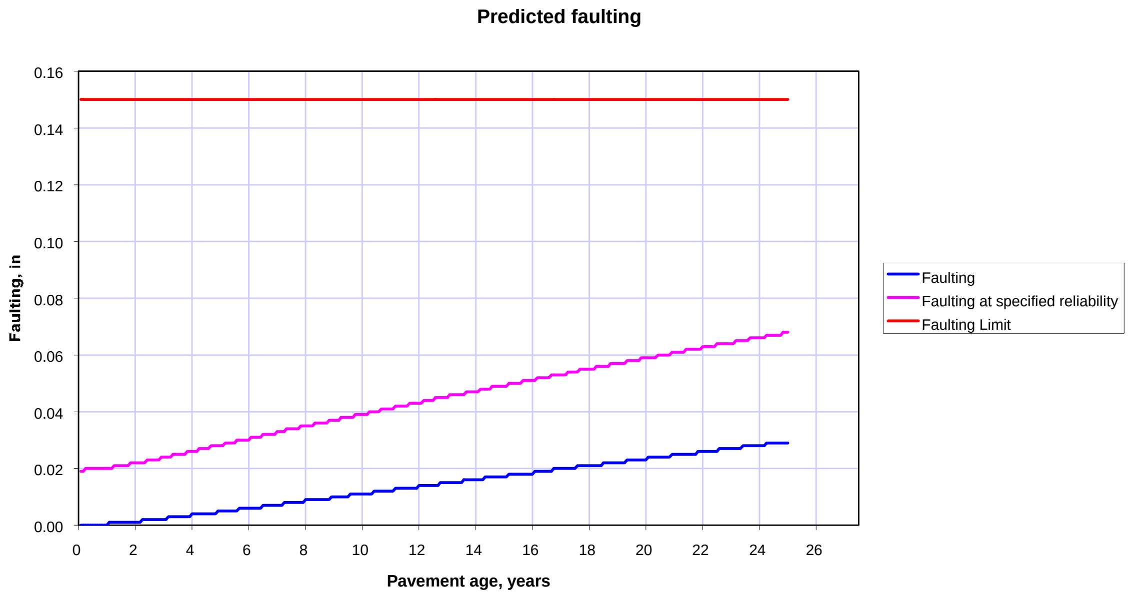


Figure D. 119. Predicted faulting at 90 percent reliability for the trial design.

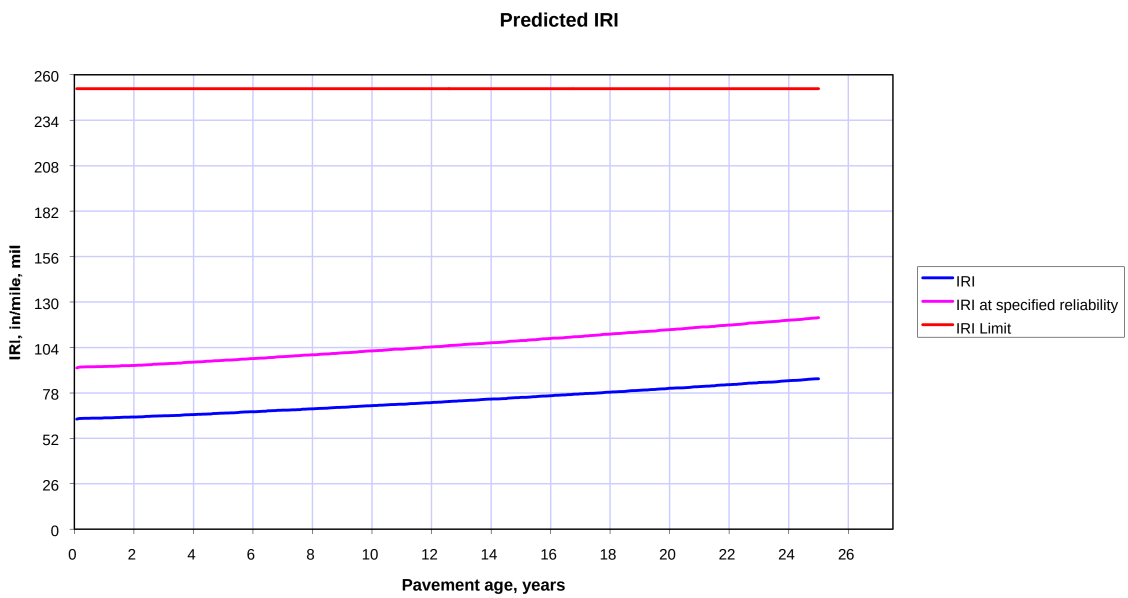


Figure D. 120. Predicted IRI at 90 percent reliability for the trial design.

This example presents a trial design, which more than satisfies the required performance criteria. However, it is very likely for the initial trial design to not be a feasible option, as a modified design might be less costly. A thinner overlay is definitely one option here.

D.5 CONVENTIONAL FLEXIBLE PAVEMENT DESIGN EXAMPLE

Design Life

The conventional asphalt concrete (AC) pavement has a 10-year design life. The base and subgrade construction will take place in August 2003, while the surface will be placed in the month of September 2003 so that the pavement can be opened to traffic in October 2003.

Construction Requirements

Assuming a good quality of construction, the pavement shall have an initial IRI between 50 and 75 in/mile (assume 63 in/mile for design purposes).

Analysis Parameters

It is expected that at the end of the 10-year design life, the pavement will have no more than an IRI of 172 in/mile, AC surface-down or longitudinal cracking of 1000 ft/mile, bottom-up fatigue cracking of 25 percent, AC thermal fracture (transverse cracking) of 1000 feet per mile. The total permanent deformation in the AC layer shall not exceed 0.25 inches and that in the total pavement not exceed 0.75 inches. In addition, if a chemically stabilized layer is used, the fatigue fracture in the layer shall not exceed 25 percent. These criteria are to be satisfied at a reliability level of 90 percent. Note that the design criterion for rutting is only the total rutting in the pavement. However, the rutting model requires the level of reliability in calculating rutting in the AC layer only as an input parameter. Therefore, the reliability level and rutting for the AC layer are input.

Location

The pavement is in the state of Indiana and located in the vicinity of Lafayette, IN. The depth of the water table is 15 feet at this site.

The 5-mile stretch of pavement to be designed is in the northbound lane called AC2002 between mileposts 05 + 00 to 10+00.

Traffic

The two-way average annual daily truck traffic (AADTT) on this highway is estimated to be 1500 trucks during the first year of its service. There will be two lanes in the design direction with 90% of the trucks in the design lane. Truck traffic is equally distributed in both directions (i.e. 50% of the trucks drive in the design direction). The operational speed is 60 mph.

This pavement is being designed for heavy traffic in a principal arterial/Interstate category highway and therefore the traffic consists of a high percentage of single trailer trucks. Information collected at this specific site shows that the percentage of AADTT in each vehicle class is same as the default Truck Traffic Classification 1 based on LTPP traffic data.:

Vehicle Class	Percent AADTT in Class
Class 4	1.3
Class 5	8.5
Class 6	2.8
Class 7	0.3
Class 8	7.6
Class 9	74.0
Class 10	1.2
Class 11	3.4
Class 12	0.6
Class 13	0.3

For each class of vehicle, the traffic pattern on monthly and daily bases remains the same through out the year. However, the traffic varies over a 24-hour period and is same as the national default based on LTPP data (provided in the Design Guide and the software).

After the base year, over the design life of the pavement, the traffic increases by 4.0% of the preceding year's traffic (compounded annually).

The axle load distribution is identical to the national defaults (derived from LTPP) provided with the Design Guide software for each vehicle class, axle type, load category, and months of the year.

Assume that the mean of the outer wheel edge is located 18 inches from the edge of the pavement. The traffic wander has a standard deviation of 10 inches. The pavement has a standard design lane width is 12 feet. The number of single, tandem, tridem and quad axles for each vehicle class is also same as the national defaults derived from LTPP data (provided in the Design Guide and the software).

The axle configuration is as follows:

Average axle width (edge-to-edge outside dimensions, ft): 8.5
Dual tire spacing (in): 12

The single and dual tire pressures are 120 psi. The design lane is 12 feet wide. The average axle spacing for tandem, tridem and quad axles are as follows:

Axle Type	Axle Spacing (in)
Tandem	51.6
Tridem	49.2
Quad	49.2

Drainage and Surface Properties

The geometric design of the highway calls for a cross slope of 2 percent. The drainage path will have a length of 12 feet from the centerline to the edge drain adjacent to the lane-shoulder joint, and the infiltration will depend on the chosen shoulder type. Assume a surface shortwave absorptivity of 0.85.

Asphalt Material Properties

The asphalt concrete mix to be used in this project has material property information in compliance with level 3 inputs for the Design Guide. Sieve analysis results for the aggregate to be used in the mix suggest that the ¾”, 3/8”, and #4 size sieves have 12, 38, and 50 percentage aggregate retained on them respectively. 4 percent passes through the #200 sieve. A PG grade 64-22 or 64-28 binder will be used for the asphalt mix design.

The volumetric design of the mix includes 12 percent binder content, 6 percent air voids, and the mix has a unit weight of 143 lb/ ft^3. Assume a thermal conductivity of 0.67 BTU/hr-ft-^oF and a specific heat of 0.23 BTU/lb-^oF. Also assume that the poison’s ratio is 0.35. The reference temperature is 70 deg F.

Subgrade

The subgrade in this location is classified as A-7-6 per the AASHTO classification system, and has a M_r value of 10,000 psi estimated at optimum conditions. The plasticity index of the soil is 40. Results from sieve analysis of this subgrade soil indicated that 90% of the material passes the #200 sieve, and 99% the #4 sieves. The D_{60} of this material is 0.01mm:

Other layers

The available base and subbase materials for this project are classified as A-1-a and A-2-5, with modulus of 40,000 psi and 28,000 psi at optimum moisture content respectively. The A-1-a and A-2-5 materials have a PI of 1.0 and 2.0, have 3% and 20% passing the #200 sieve, 20% and 80% passing the #4 sieve, and have D_{60} values of 8 and 0.1mm respectively.

Trial Design

The Design Guide procedure is an iterative procedure and requires the user to develop a trial design to begin the design process. The trial design is analyzed over the design period specified by the designer, and the Design Guide software predicts the performance of the trial design. If the design criteria are not met, then the design is suitably modified till a final design is achieved. The design process requires the following steps:

D.5.1 Create a New project

D.5.1.1 Create a new design project in the Design Guide program

Open the Design Guide program from the *Programs* menu of the operating system (windows 98, 2000, XP, NT). Next open a new file and assign a name to the project, "*AC Conventional Example*" as shown in Figure D.121. Next, select the folder to store the design files as "*C:\DG2002\Projects*". Select US Customary units as the measurement system by clicking the radio button next to it. Next, click "*OK*" and the program opens the main layout screen of the design project as shown in Figure D.122.

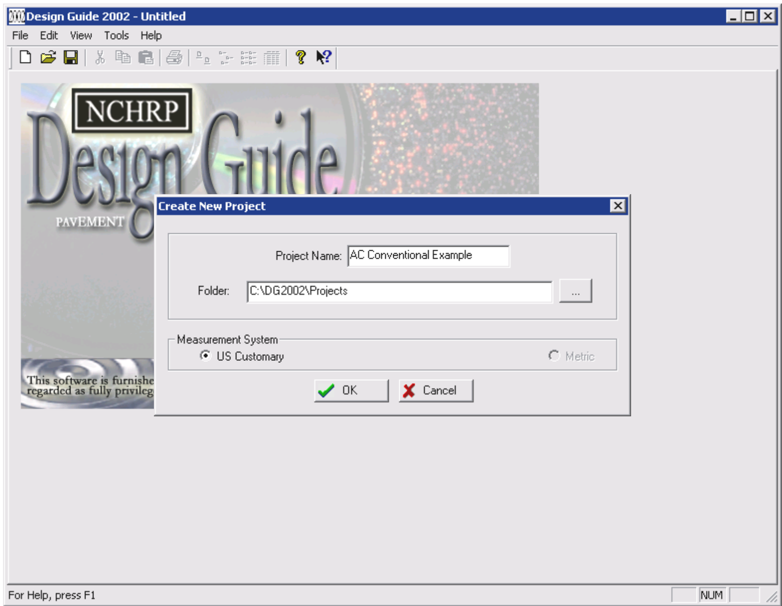


Figure D.121. Create a new project file from the main program.

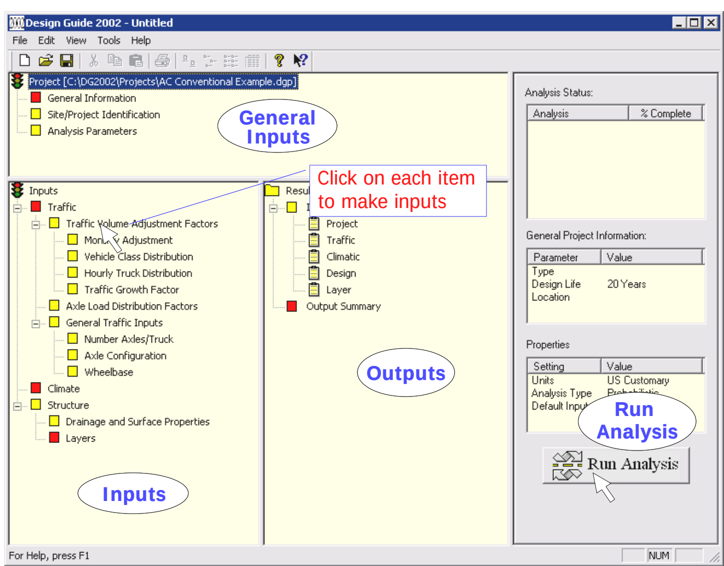


Figure D.122. Main program layout.

D.5.2 General Inputs

D.5.2.1 *General Information*

On the main project screen click on the *General Information* input to open the *General Information* screen. Inputs on General Information Screen as shown in Figure D.123:

Design Life: 10 years
Base/Subgrade Construction Month: August 2003
Pavement Construction Month: September 2003
Traffic Open Month: October 2002
Type of Design: New Pavement – Flexible Pavement

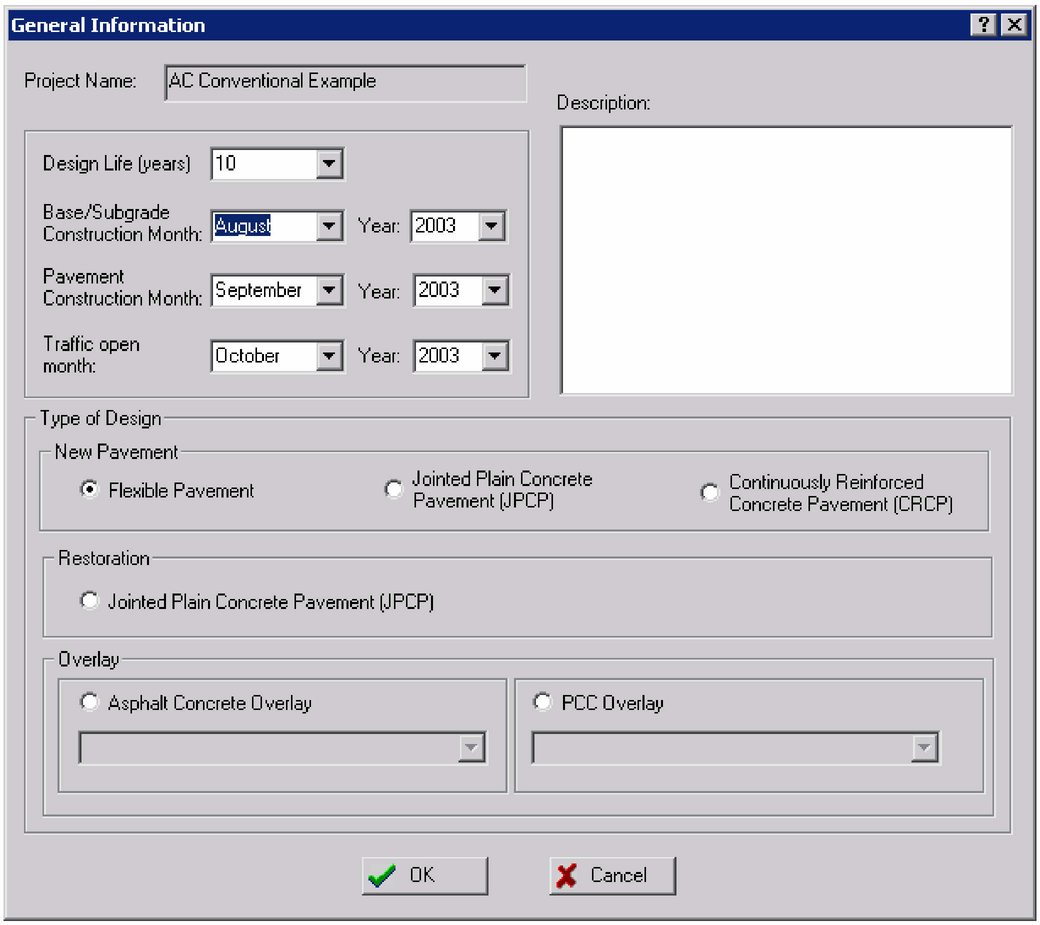


Figure D.123. *General Information* screen.

Click *OK* and return to the program layout screen

D.5.2.2 *Site/Project Identification*

Click on *Site/Project Identification* to open the *Site/Project Identification* screen. Inputs made on this screen are purely for providing identification to the project. Inputs to be made for this design, are shown in
Figure D.124, and are as follows:

Location: Indianapolis, Lafayette
Project ID: AC2002
Section ID: AC2002 - A
Functional Class (from pull-down menu): Principal Arterials – Interstate and Defense
Date: Date performing the design
Station/milepost format: 00+00
Station/milepost begin: 05 + 00
Station/milepost end: 10 + 00
Traffic Direction: Northbound

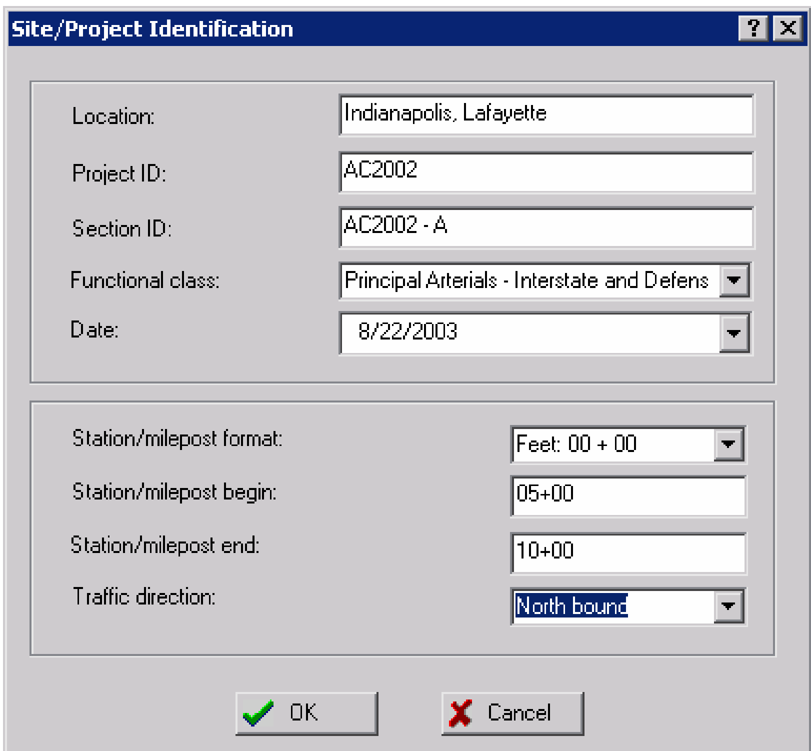


Figure D.124. *Site/Project Identification* screen.

Click *OK* and return to the main layout program.

D.5.2.3 *Analysis Parameters*

This screen allows the user to make inputs with regard to design criteria chosen by the agency. For this specific example, the inputs to be made on the *Analysis Parameters* screen, as show in Figure D.125 are as follows:

Initial IRI (in/mile): 63
Analysis Type: Probabilistic
Performance Criteria (Enter both criteria and level of reliability)
- Terminal IRI: 172 at 90 % reliability
- AC Surface Down/Longitudinal Cracking: 1000 ft/mile at 90 % reliability
- AC Bottom Up/Alligator Cracking: 25 % at 90 % reliability
- AC Thermal Fracture: 1000 ft/mile at 90 % reliability
- Chemically Stabilized Layer Fatigue Fracture: 25 % at 90 % reliability
- Permanent Deformation: 0.75 in at 90 percent reliability

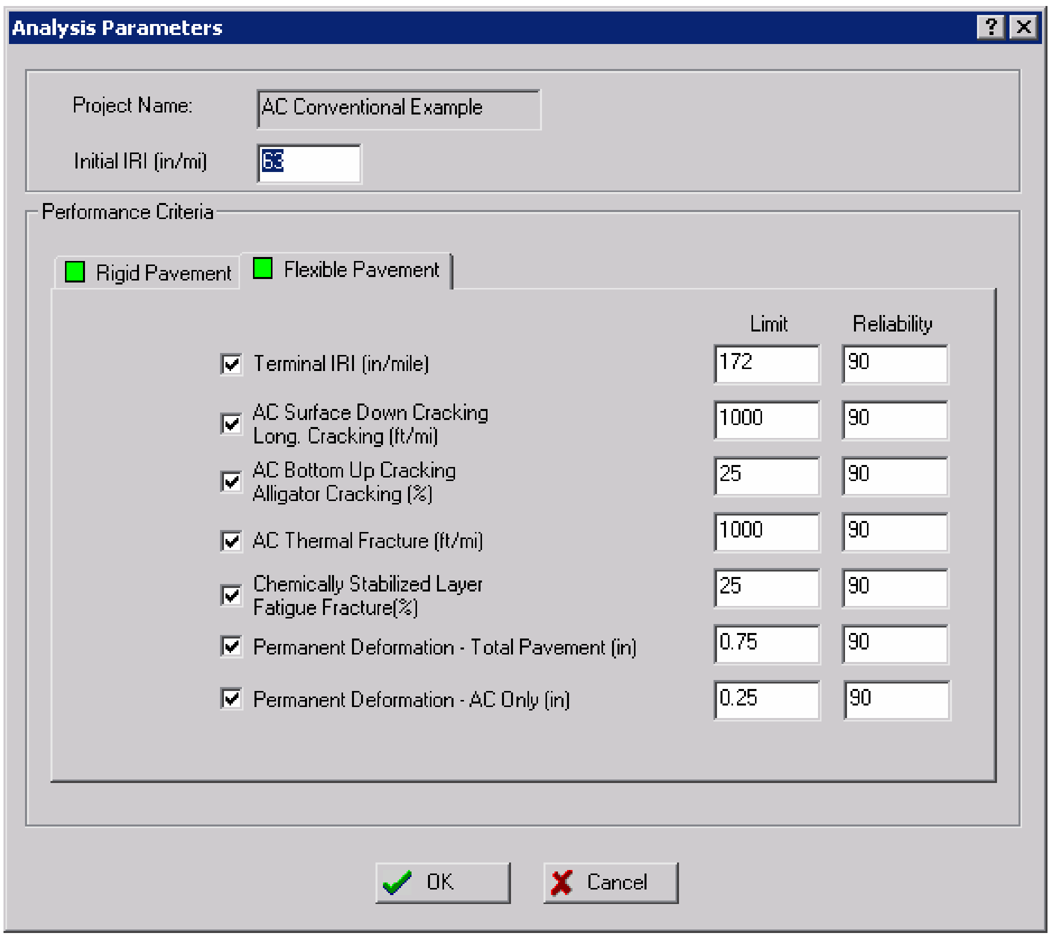


Figure D.125. *Analysis Parameters* screen for flexible pavement design.

Click *OK* and return to the main layout program. Note that the icons in the general inputs are all green at this point. It is suggested that at this point, the input file be saved by clicking on the "diskette" icon in the tool bar or by clicking *Save* on the *File* menu.

D.5.3 Traffic Inputs

D.5.3.1 *Traffic*

See 2.3.1 for description of this screen. Inputs on this screen, as shown in Figure D. 126 are as follows:

Two way average annual truck traffic: 1500
Number of lanes in design direction: 2
Percent of trucks in design direction: 50
Percent of trucks in design lane: 90
Operational truck speed: 60

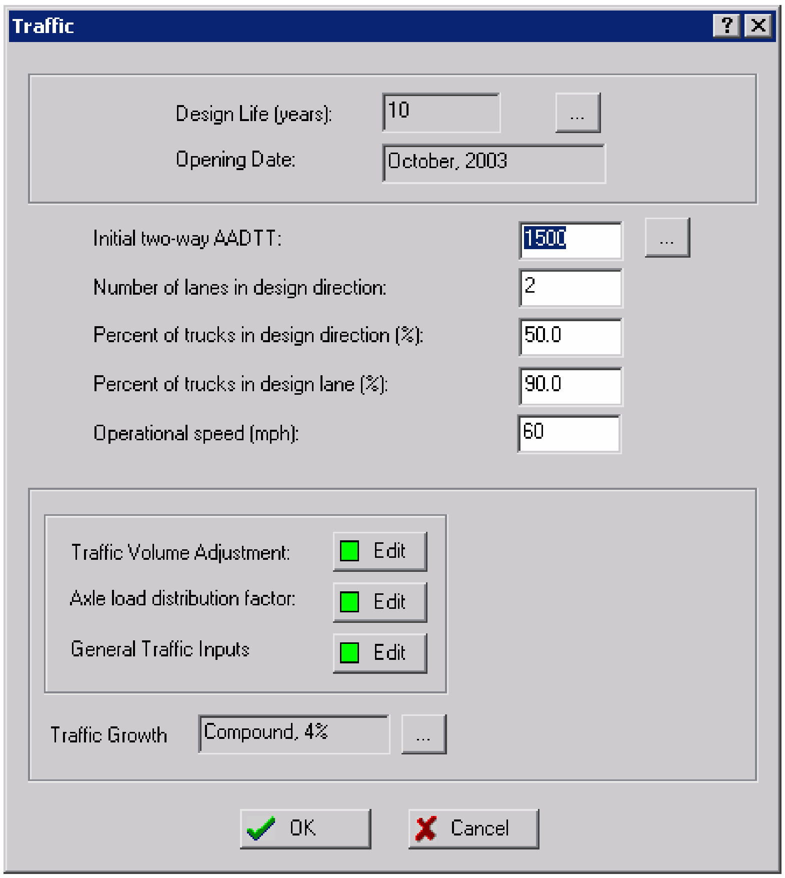


Figure D. 126. *Traffic* screen.

Click *OK* and return to the main layout program.

D.5.3.2. *Traffic Volume Adjustment Factors*

The Traffic Volume Adjustment Factors screen has 4 property pages (or sub-screens), namely:

- *Monthly Adjustment*
- *Vehicle Class Distribution*
- *Hourly Distribution*
- *Traffic Growth Factors*

D.5.3.2.1 *Monthly Adjustment*

The inputs on this screen indicate the distribution of traffic over the different months of a year for each traffic class. The Monthly Adjustment Factor (MAF) is the proportion of AADTT occurring over a 24-hour period in each month for each vehicle class.

For this example, since the traffic distribution remains the same through out the year, i.e. does not change between the different months of the year, the default monthly adjustment factors can be used.

Click on the radio button for Level 3 default inputs as shown in Figure D.127. Note that the default MAF value is 1.0 for all months in each vehicle class.

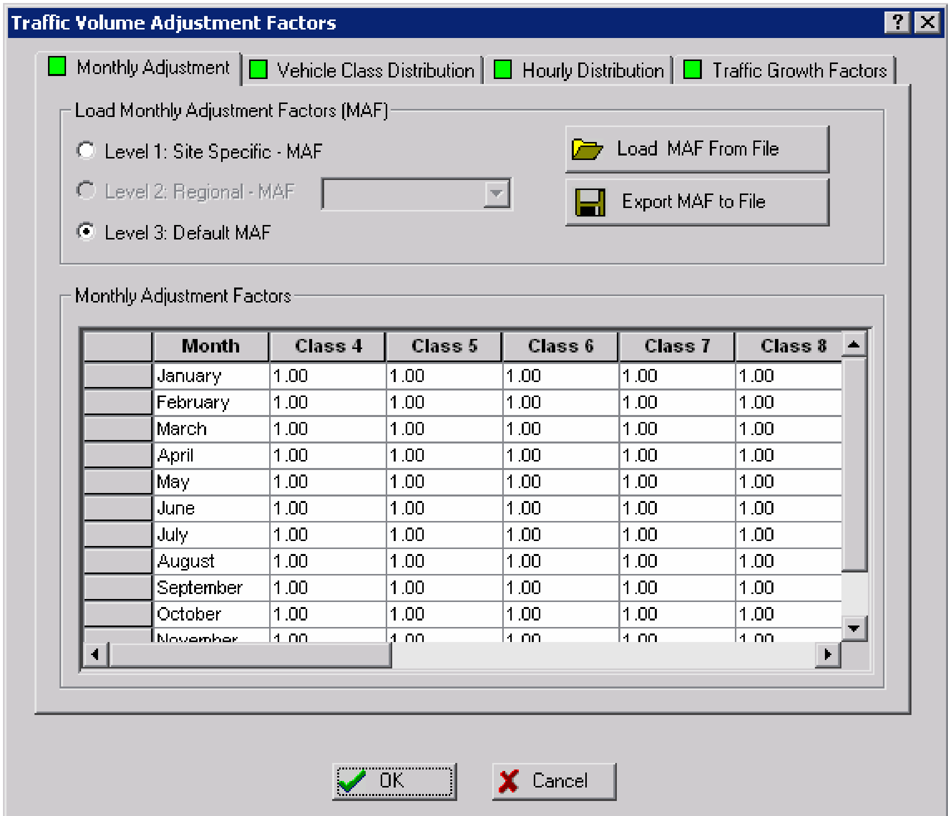


Figure D.127. *Monthly Adjustment Factors* screen.

Next click on the *Vehicle Class Distribution* tab.

D.5.3.2.2 *Vehicle Class Distribution*

Site-specific vehicle class distribution data is available for this design project. Click on the radio button *Level 3: Default Distribution* and click on the *Load Default Distribution* button. Select *pavement category* as *Principal/Arterials-Interstate and Defense* and choose Truck Traffic Classification or *TTC* #1 listed in the 10th row of the table as shown in Figure D. 128. This TTC has a high percentage of vehicles in Class 9 (single trailer trucks). Click *OK* and return to the *Vehicle Class Distribution* screen. As shown in Figure D. 129, the TTC 1 distribution by vehicle class is seen on the screen. Next, click on the *Hourly Distribution* tab.

D.5.3.2.3 *Hourly Distribution*

Enter the hourly distribution of the AADTT as shown in Figure D. 130. Next, click on the *Traffic Growth Factors* tab.

D.5.3.2.4 *Traffic Growth Factors*

The given data suggests that the traffic grows 4.0 % at a compound rate. The program will use a default function for traffic growth at a compound rate. Select *Compound*

Growth and enter a growth rate of 4.0 % as shown in Figure D.131. Note that the previously entered traffic inputs appear, but are grayed out, on the screen.

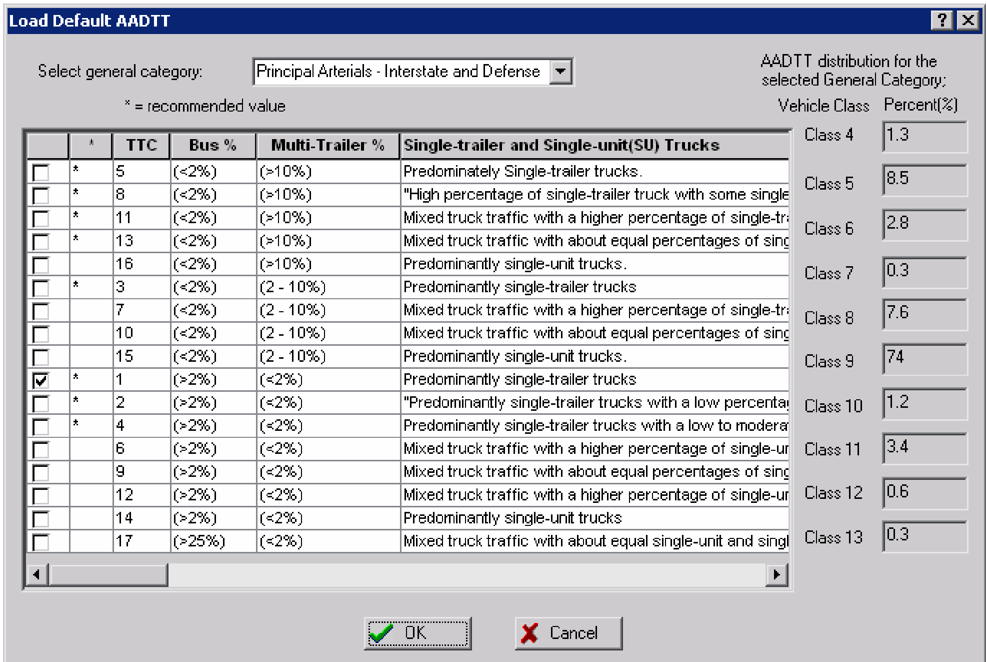


Figure D. 128. *Load Default AADTT* screen.

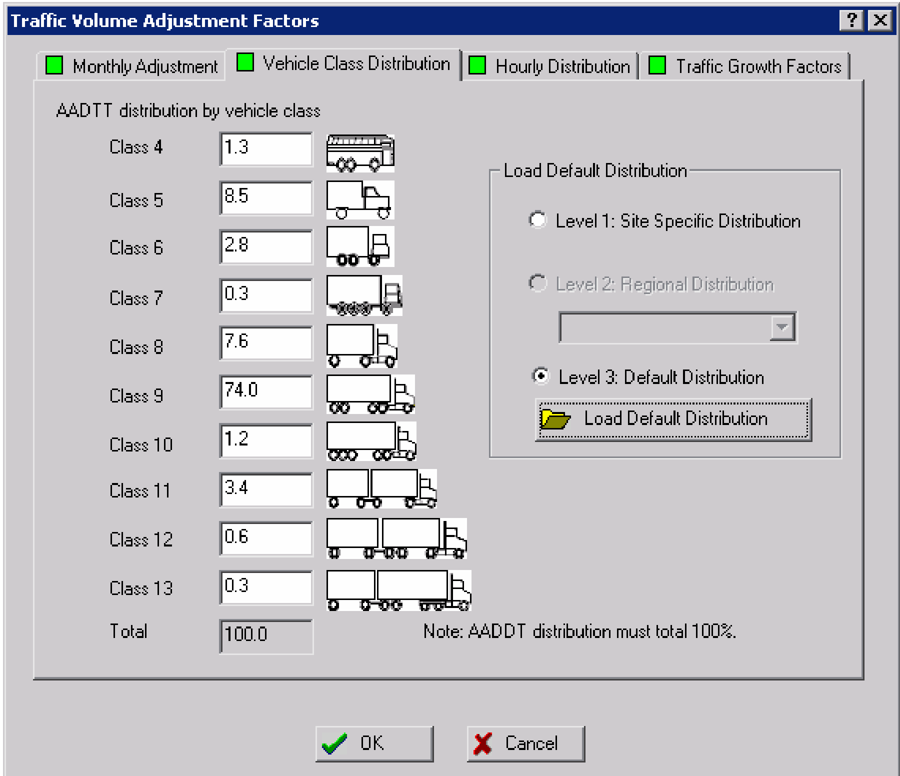


Figure D. 129. *Vehicle Class Distribution* screen.

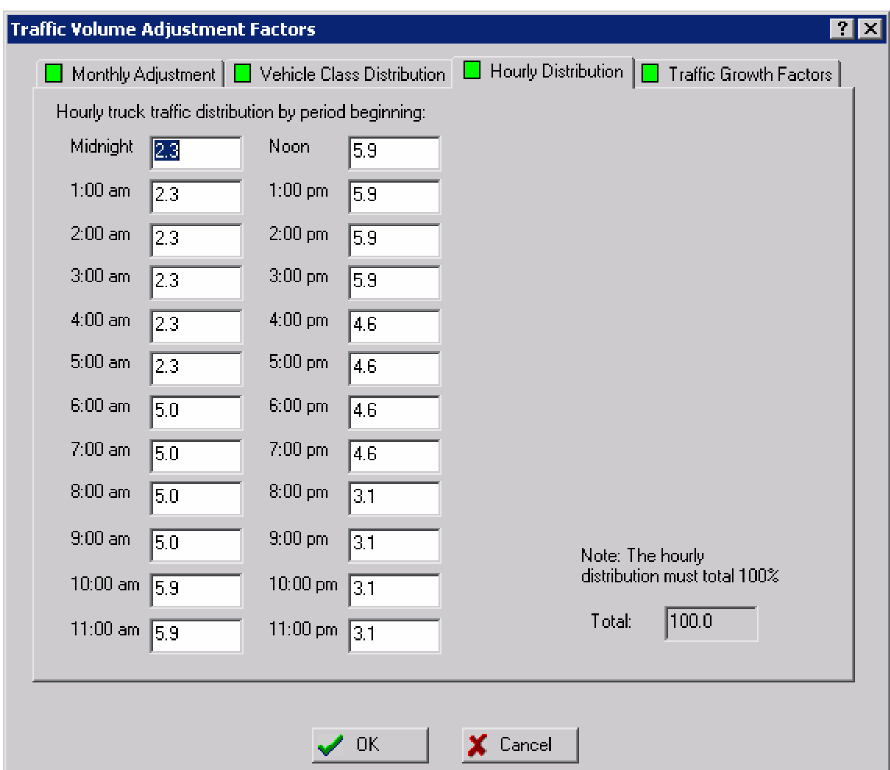


Figure D. 130. *Hourly Distribution* screen.

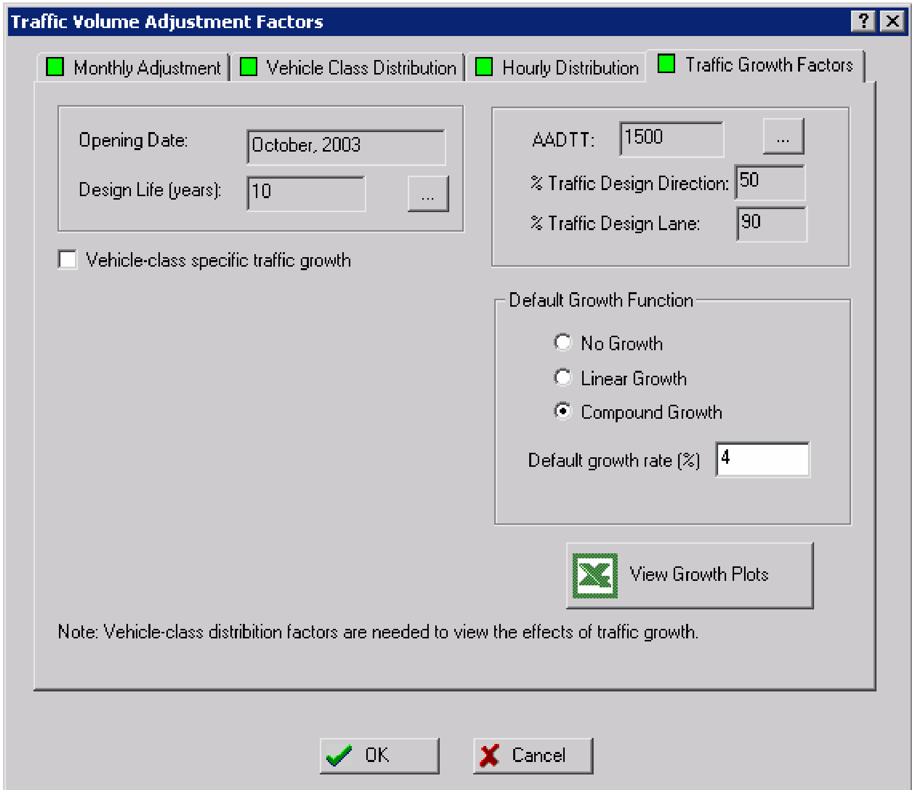


Figure D.131. *Traffic Growth Factors* screen.

Next click on *View Growth Plots* to open a Microsoft Excel spreadsheet that shows the growth in AADTT for each vehicle class over the design life. The plots are shown in Figure D.132, Figure D.133, and Figure D.134 for vehicle classes 4-7, 8-10, and 11-13 respectively. Close the Excel spreadsheet and click *OK* on the *Volume Adjustments* screen to return to the main layout page.

D.5.3.3 *Axle Load Distribution Factors*

This screen allows the user to specify the percentage of vehicles in each vehicle class, at each load level, for each axle type. This design example uses the default LTPP distribution and therefore the level 3-default input will be used. Click on the radio button for level 3 axle load distribution factors as shown in Figure D. 135. The program automatically loads default values for these inputs. Click *Ok* to return to the main screen.

Note that the program also allows exporting a previously saved file if the user so chooses.

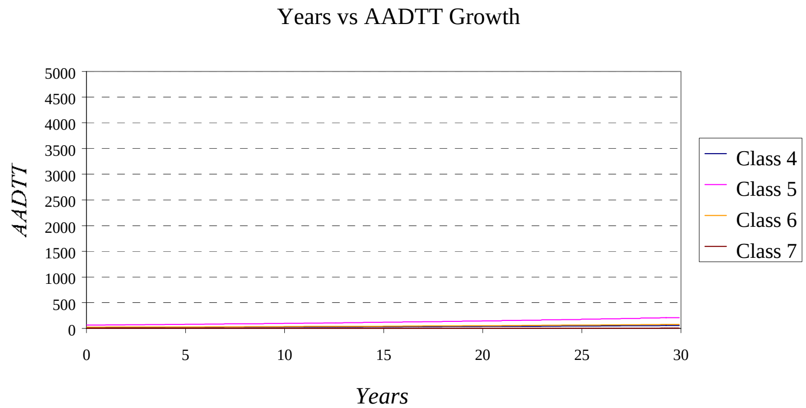


Figure D.132. Growth in AADTT for Vehicle classes 4 through 7.

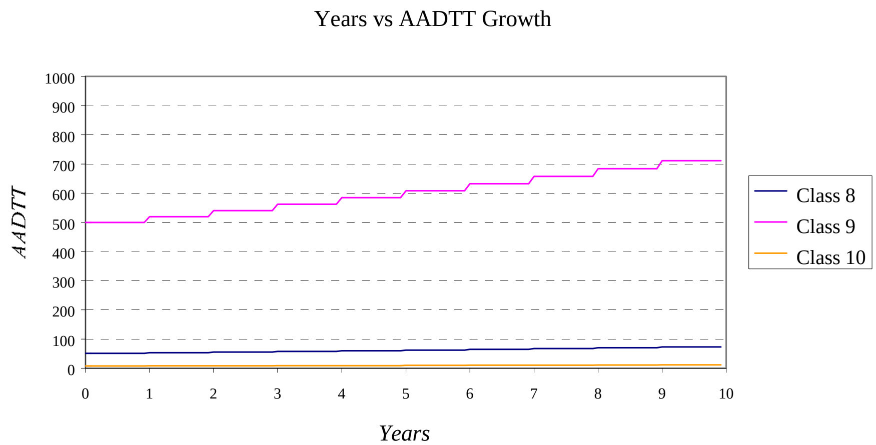


Figure D.133. Growth in AADTT for Vehicle classes 8 through 10.

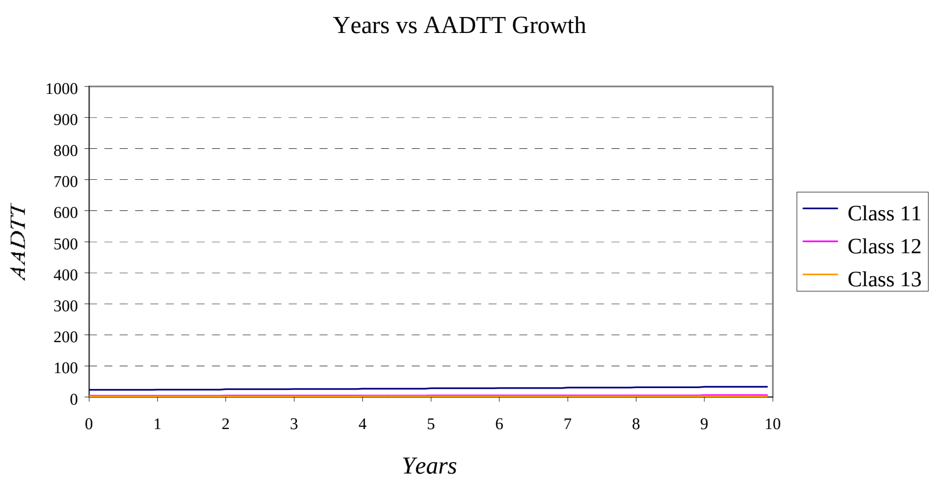


Figure D.134. Growth in AADTT for Vehicle classes 11 through 13.

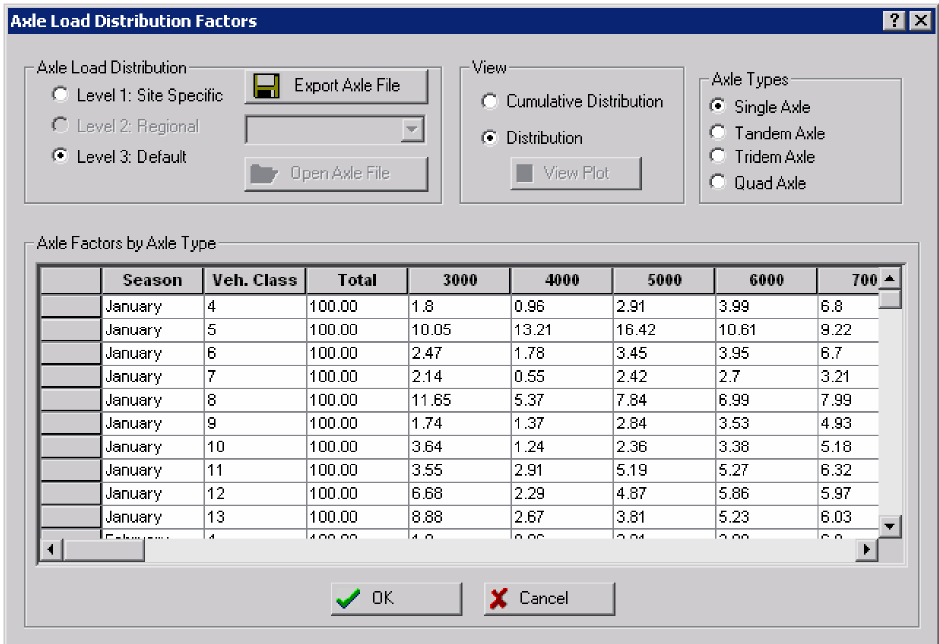


Figure D. 135. *Axle Load Distribution Factors* screen.

D.5.3.4 *General Traffic inputs*

This screen allows the user to provide traffic wander inputs and also has 3 property pages, namely,

> *Number of Axles/Truck*
> *Axle Configuration*
> *Wheelbase*

Enter the following inputs for lateral traffic wander as shown in Figure D. 136.

> Mean wheel location: 18 inch
> Traffic wander standard deviation: 10
> Design lane width: 12 feet

D.5.3.4.1 *Number Axles/Truck*

Enter the number of axles per truck as shown in Figure D. 136:

D.5.3.4.2 *Axle Configuration*

Enter the following inputs on the *Axle Configuration* property page as shown in Figure D. 137:

> Average axle width: 8.5 feet
> Dual tire spacing: 12 in

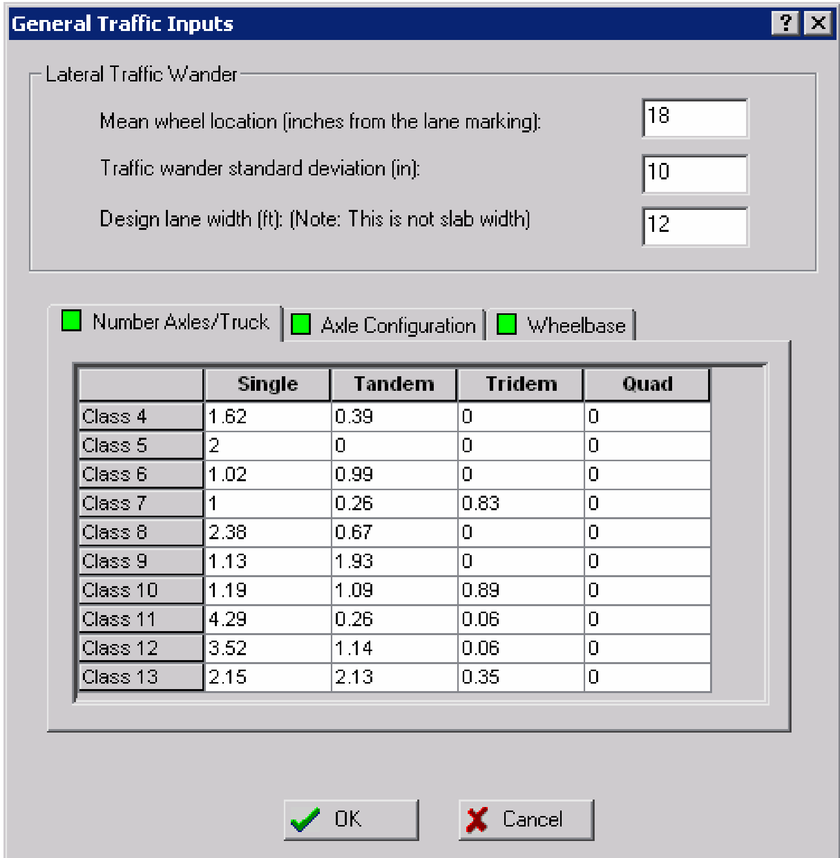


Figure D. 136. General Traffic Inputs – Number of Axles/Truck.

Tire pressure:
- Single tire: 120 psi
- Dual tire: 120 psi

Axle spacing:
- Tandem axle: 51.6 in
- Tridem axle: 49.2 in
- Quad axle: 49.2 in

D.5.3.4.3 *Wheelbase*

Enter the following inputs on the *Wheelbase* property page as shown in Figure D. 138:

Average axle spacing
- Short: 12 feet
- Medium: 15 feet
- Long: 18 feet

Percentage trucks
- Short: 2.0 percent
- Medium: 20.0 percent
- Long: 78.0 percent

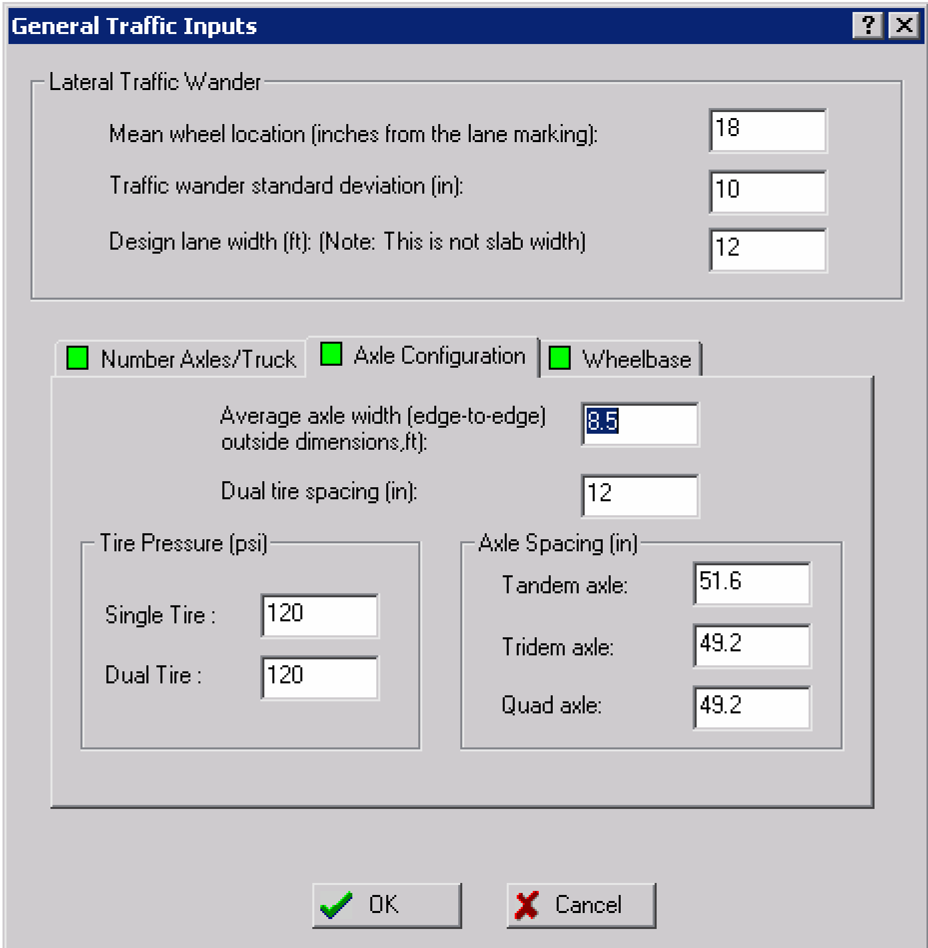


Figure D. 137. *General Traffic Inputs – Axle Configuration* screen.

Click *OK* and return to the main program layout screen. The user, by this stage, has made all traffic inputs and is now ready to make Climate inputs for the project. Save the project file before proceeding.

D.5.4 Climate Inputs

<u>D.5.4.1 *Climate*</u>

There are several methods of making climate inputs to the program, depending upon the extent of information available, regardless of the pavement type. Sections D.2.4.1 and D.3.4.1 address these other methods.

This design example, although does not specify the exact project location, provides details of the general vicinity of the project, i.e. Lafayette, Indiana. The user can either import a previously generated climatic data file, or generate one for a specific location. In this case, the user will have to generate a new file (unless the example is being rerun with a previously generated file).

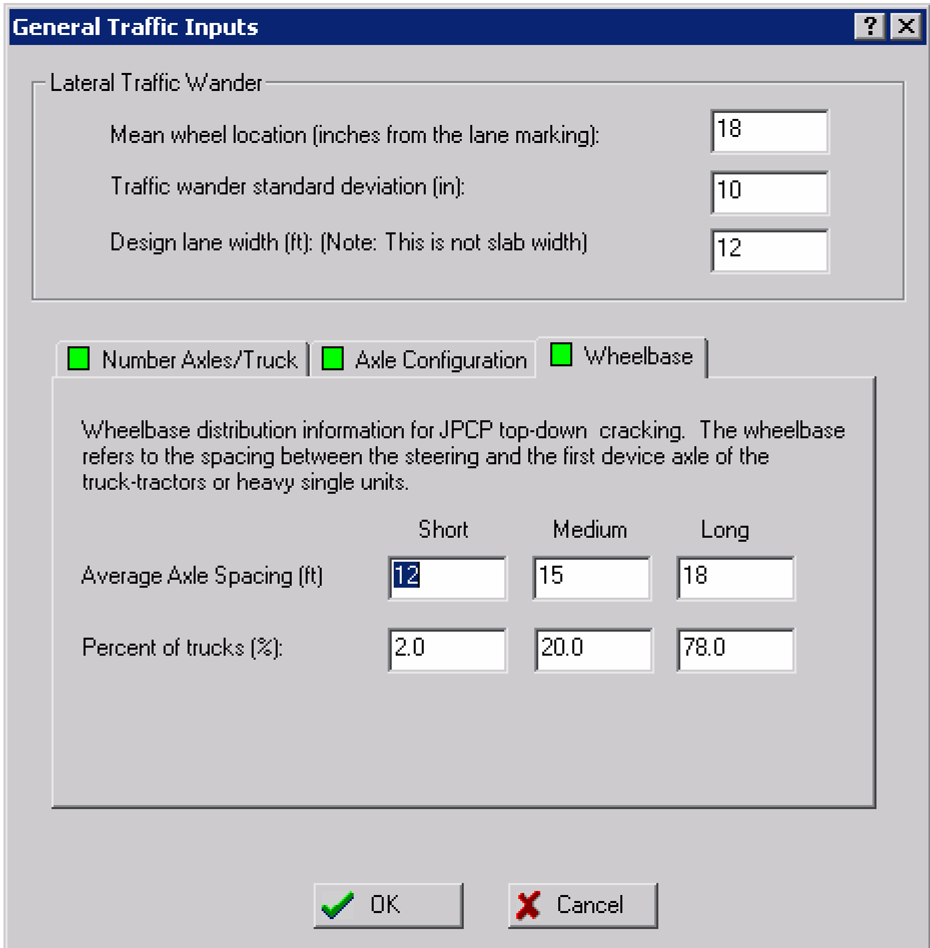


Figure D. 138. General Traffic Inputs – Wheelbase screen.

Click on *Climate* on the main project layout screen. On the main *Climate* screen, as shown in Figure D. 139, click on *Generate* to generate a new climatic data file. Then click on the radio button *Climatic data for a specific weather station*. From the list of weather stations in the database, choose Lafayette, IN, and enter a water table depth of 15 feet as shown in Figure D. 140.

The screen shown in Figure D. 140 indicates that this station contains 48 months of weather data. The current EICM contains 66 months of weather data for a section with complete weather data. If the number of months of available data is less than that of the complete data set, it will be necessary to interpolate weather information from nearby weather stations for those months when data becomes unavailable. Now click on the radio button for *Interpolate climatic data for given location*. The program automatically lists the six closest weather stations in the database that is within a radius of 100 miles. Climatic data is interpolated from those weather stations that are selected on this screen.

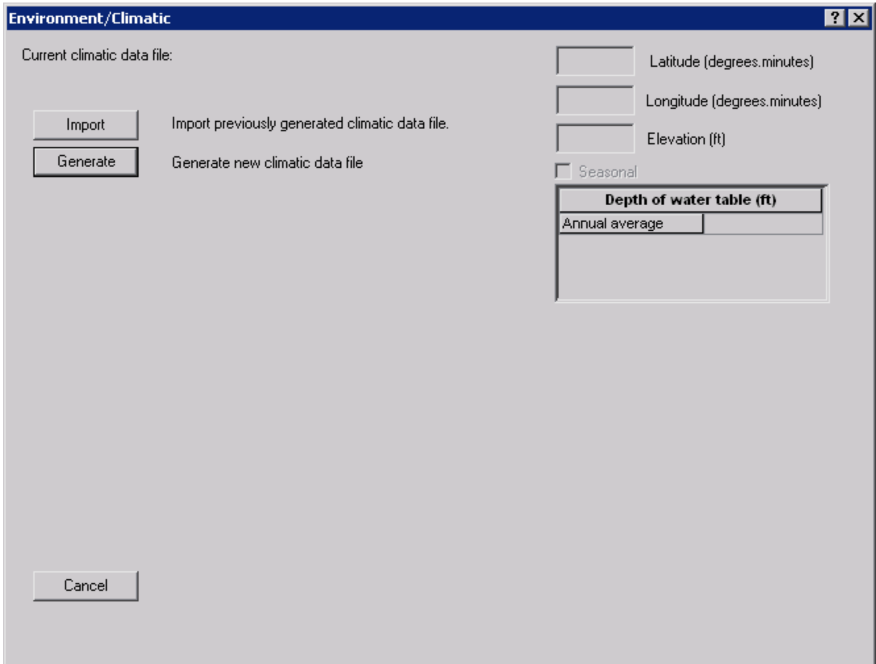


Figure D. 139. Main *Climate* screen.

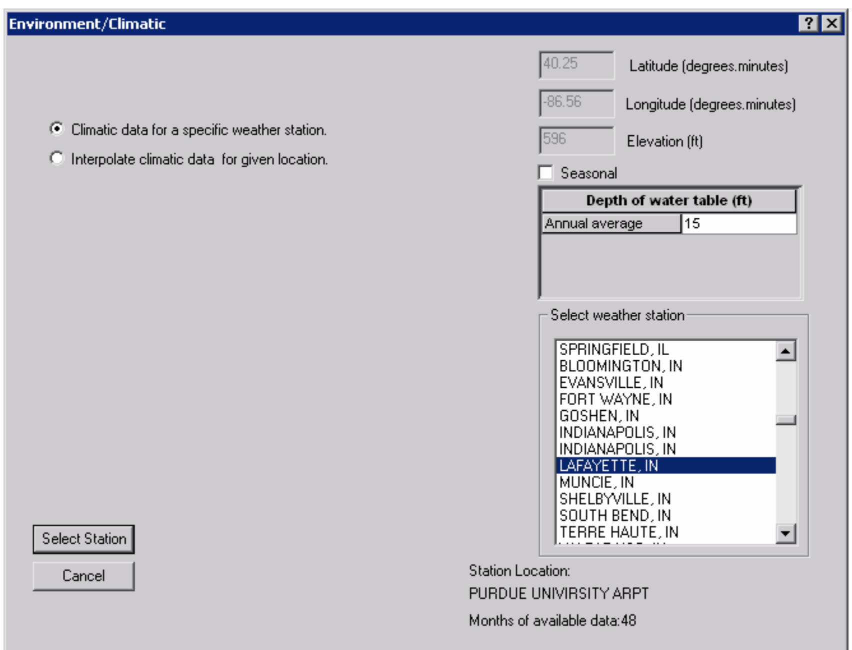


Figure D. 140. Generating climatic data file for the project location.

The program also lists the distance of each weather station from the actual location (i.e. Lafayette, IN). The weather data is interpolated for the given location inversely weighted by the square of the distance. Therefore for the 48 months when data is available, based on a weight of 100 percent for "0" distance, the actual data from Lafayette will be used. For the months with missing data, the data will be interpolated.

Note the considerations for selecting weather stations in this process as discussed in 3.4.1. For the purpose of this example, select all listed weather stations and click on the *Generate* button. The program creates the climatic data file for the project. After the climatic data file is created, the program prompts the user to save it. Save the file in the project directory - *"C:\DG2002\Projects\AC Conventional EXAMPLE\lafayette.icm"*.

Note that the program also automatically creates a file called *climate.tmp* in the project directory. This is the file that the program reads hourly climatic information from during the analysis stage. This file contains the sunrise time, sunset time and radiation for each day of the design life period. In addition, for each 24-hour period in each day of the design life, the temperature, rainfall, air speed, sunshine, and depth of ground water table are also listed in the climate file.

By this stage, the user has completed the climatic inputs required for the program. The color-coded icons will have a green color for the traffic and climate and red icons for structure, indicating that the traffic and climate inputs are complete and structural inputs are yet to be addressed.

D.5.5 Structural Inputs

The user at this stage needs to choose structural parameters and a layer combination that can be evaluated for its performance. As explained in the PART 3 of the Guide, the procedure is an iterative procedure and the user will have to develop a trial design first, make several modifications to it next, and finally arrive at a feasible and economic (or final) design.

Based on the available materials for the different layers, choose the following layers in the trial design:

3.0-inch AC layer
6.0-inch A-1-a granular base layer
9.0-inch A-2-5 compacted subbase layer
Semi-infinite uncompacted (natural) A-7-6 subgrade layer

The structural inputs are of three categories, *Drainage and Surface Properties*, *Layer Properties*, and *Thermal Cracking*,. These three categories of inputs have direct links from the main program layout screen.

D.5.5.1 *Drainage and Surface Properties*

From the main program layout screen click on *Drainage and Surface Properties* to open the screen shown in Figure D. 141.

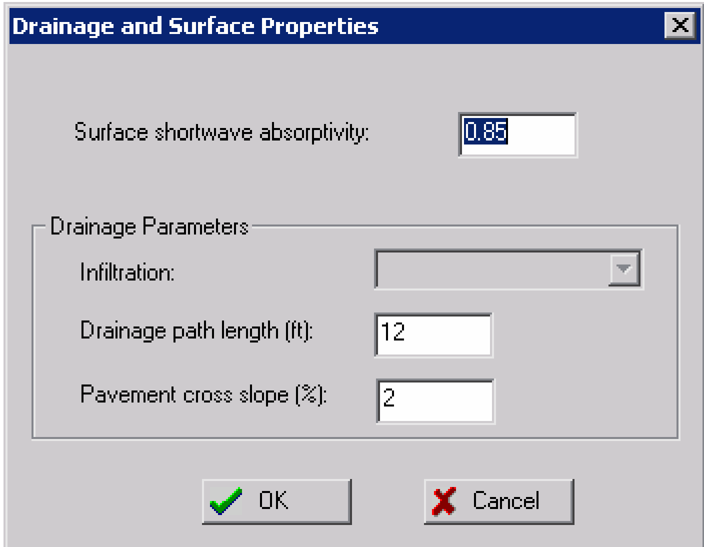


Figure D. 141. *Drainage and Surface Properties* screen.

Enter 0.85 for *surface shortwave absorptivity*., 12 feet for D*rainage path length* and 2 percent for *Pavement cross slope*. Note that the flexible pavement design does not require the user to input *Infiltration*. Click *Ok* and return to the main program layout.

D.5.5.2 *Layers*

On the main program layout screen, click on *Layers* to add and edit pavement layers in the trial design. The program opens the *Layers* screen as shown in Figure D. 142. Refer to section D.2.5.3 for a discussion on the *Insert, Delete and Edit* functions that can be performed from this screen.

The first layer of the pavement, the AC layer is shown on the screen in Figure D. 142. Next, the user has to add a layer after (underneath) the AC layer. To add a layer after the AC layer, select layer 1 by clicking on the row shown for Layer 1 and then insert a layer by clicking on the *Insert* button. The program now opens a screen shown in Figure D. 143a that allows the user to select the layer to be added.

As shown in Figure D. 143 b, from the scroll down menu select *Granular Base* for the *Material Type*, *A-1-a* for the *Material*, and enter *6.0* for the *Thickness*. Next, click *Ok* to return to the *Layers* screen shown in Figure D. 144. This screen now shows the newly added granular base layer.

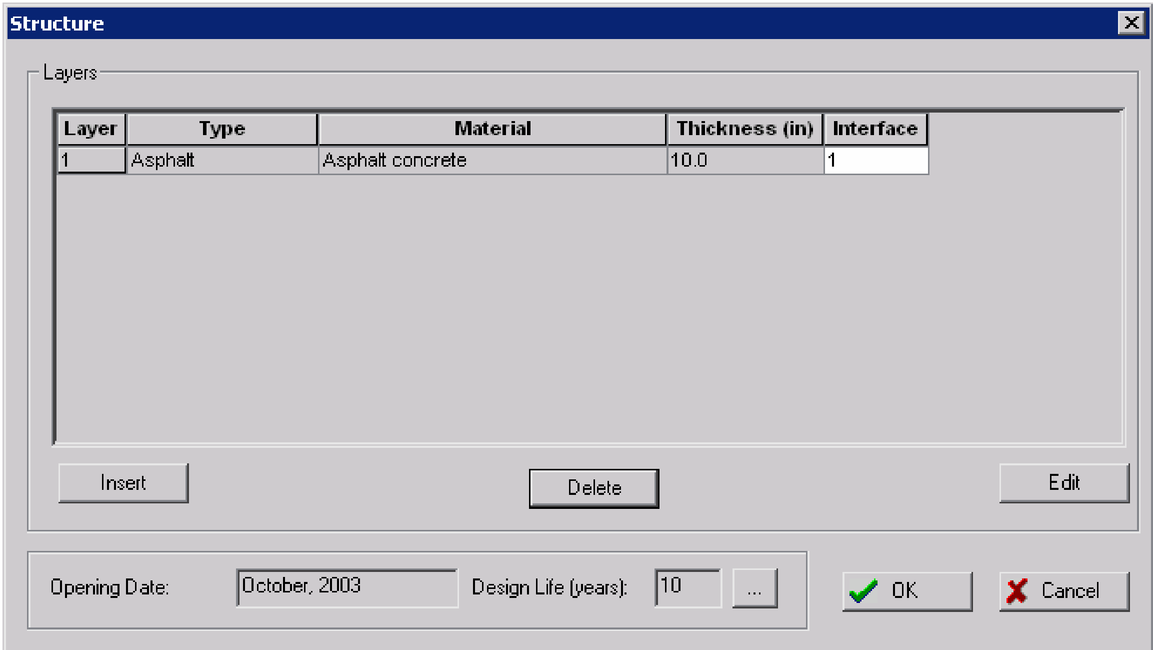
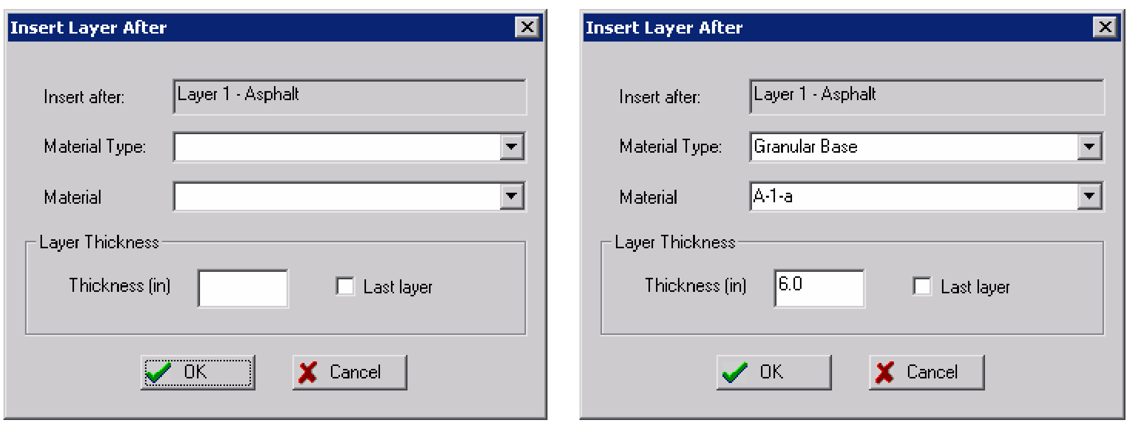


Figure D. 142. *Layers* screen.



a) Initial screen to insert layer

b) Inputs to insert cement stabilized layer

Figure D. 143. Inserting granular base layer after AC layer.

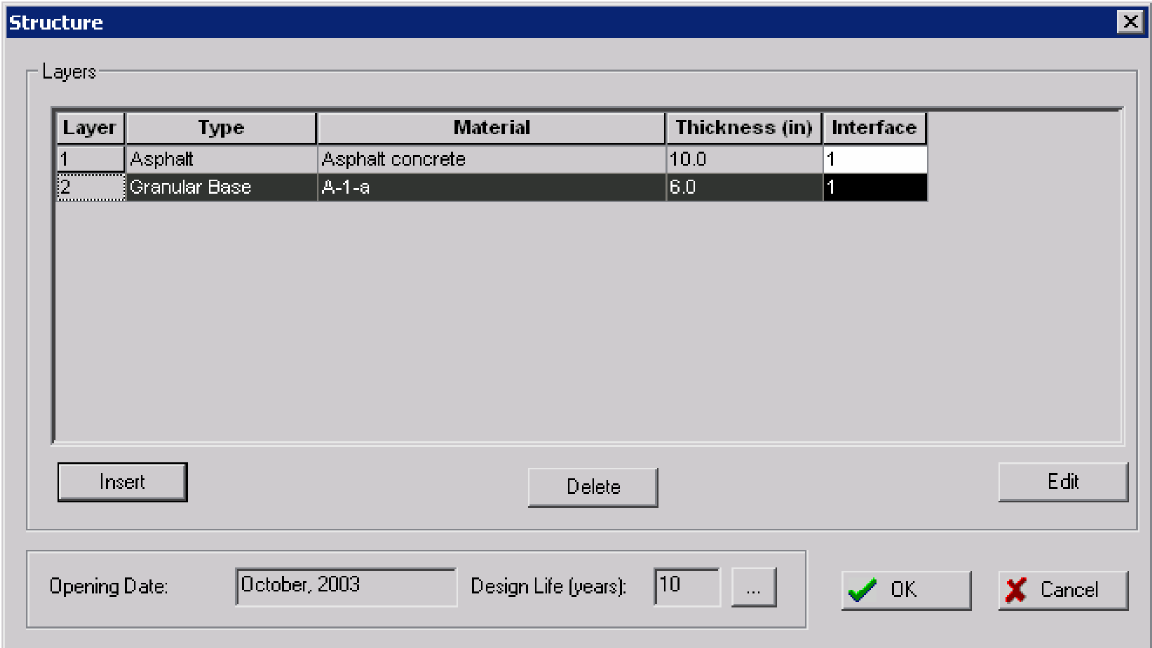


Figure D. 144. Layers screen after inserting the base layer.

Next, select layer 2 and click *Insert* to add a layer after the A-1-a granular layer. Select *Granular Base* for the *Material type* and *A-2-5* for *Material* as shown in Figure D. 145. Enter a thickness of 9.0 inches Click *Ok* and return to the *Layers* screen.

Repeat the same steps again and add the A-7-6 subgrade layer as shown in Figure D. 146. Select the *last layer* option instead of entering a thickness to this layer. Click *Ok* and return to the Layers screen that now shows all four layers added to the structure as illustrated in Figure D. 147.

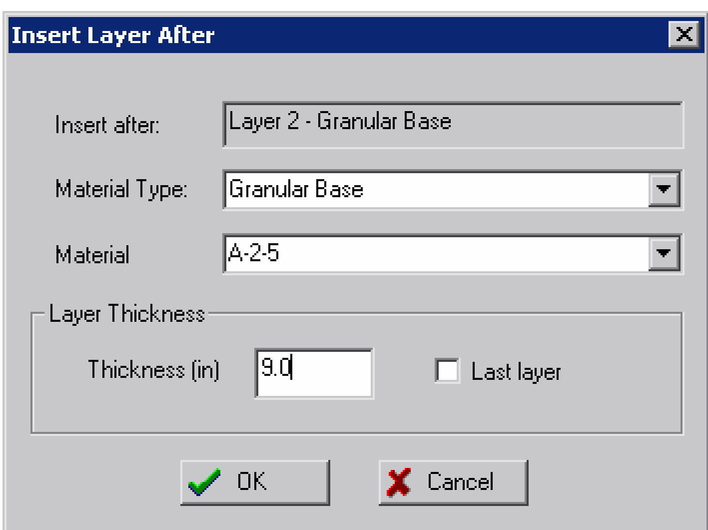


Figure D. 145. Inserting the compacted subgrade layer after the asphalt base layer.

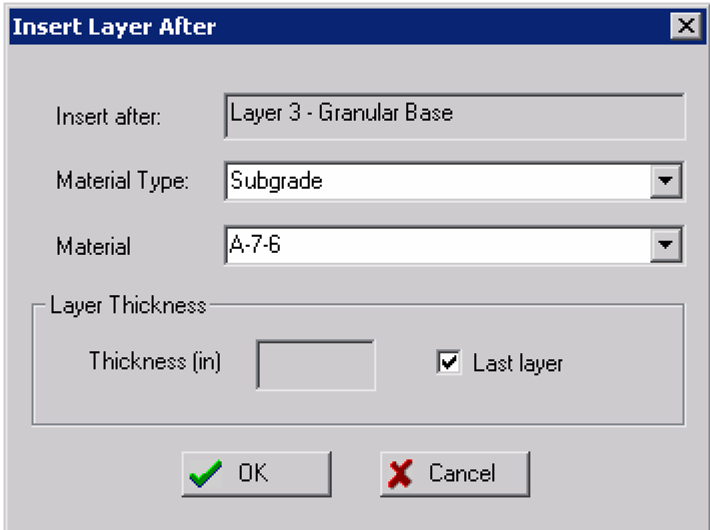


Figure D. 146. Inserting the uncompacted subgrade layer after the compacted subgrade.

The individual screens for the input of layer material properties can be accessed either from the *Layers* screen shown in Figure D. 147, or directly from the program layout screen. To access the material properties screen from the *Layers* screen, select the desired pavement layer and click on *Edit*. To return to the program layout screen, click *Ok* on the *Layers* screen. The program layout screen is shown in Figure D. 148.

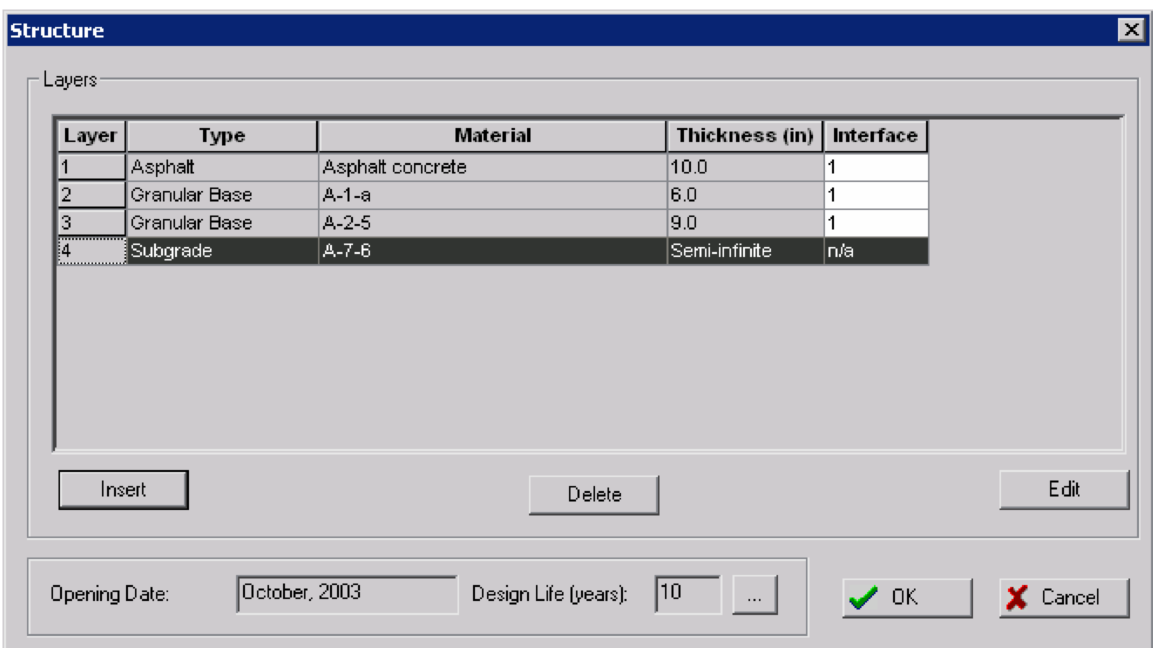


Figure D. 147. Layers screen after the addition of all layers.

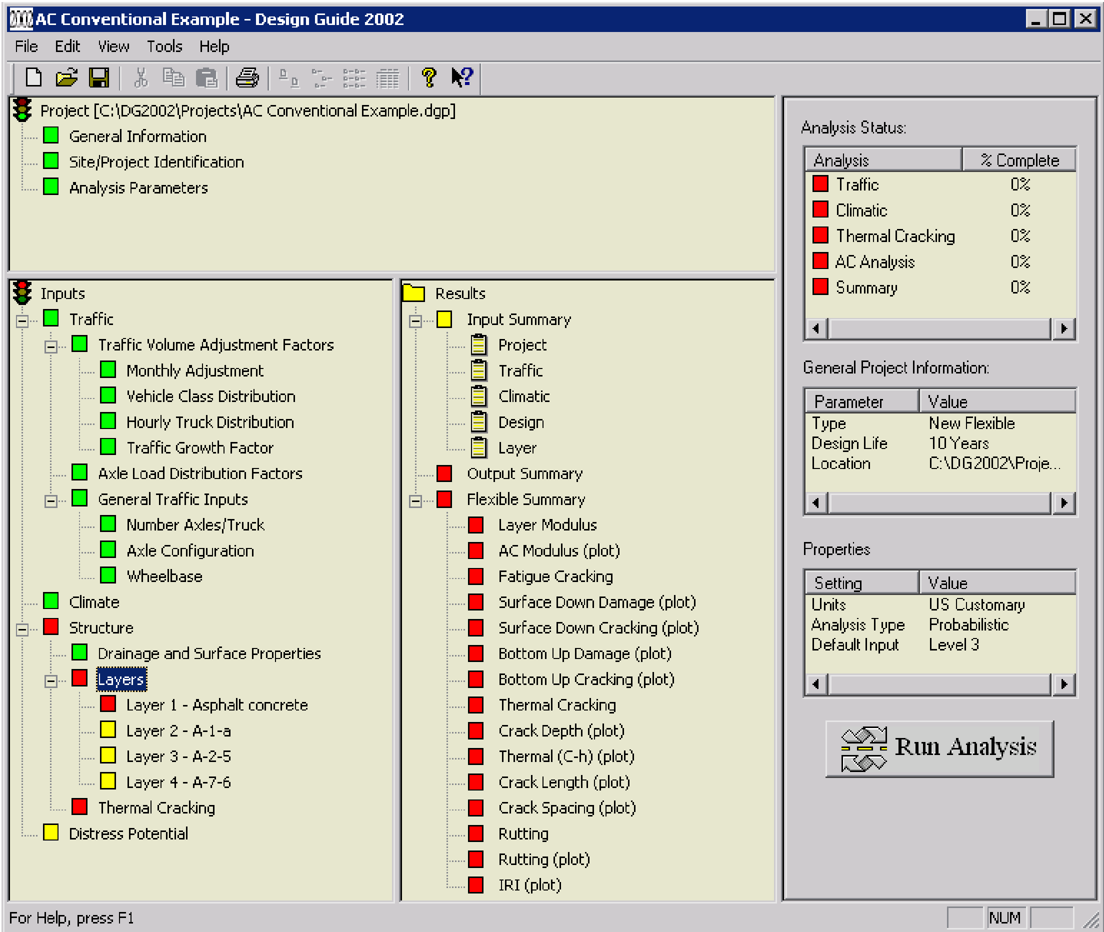


Figure D. 148. Program layout screen after adding all layers.

<u>D.5.5.2.1 *Layer 1 – Asphalt Concrete*</u>

Click on *Layer 1 – Asphalt Concrete* to edit AC layer material properties. This opens a screen with three property pages for *Asphalt Mix, Asphalt Binder*, and *Asphalt General* properties. The main screen also allows the user to input the layer thickness, and select the level of inputs that the designer is using for AC properties. Enter a thickness of 3 inches for the AC layer and choose level 3 inputs from the draw down menu. Further, on the property page *Asphalt Mix,* enter the gradation of the aggregates used in the mix design as shown in Figure D. 149:

Cumulative % retained on ¾" sieve = 12
Cumulative % retained on $^3/_8$" sieve = 38
Cumulative % retained on #4 sieve = 50
Percent passing #200 sieve = 4

After completing the above inputs on the A*sphalt Mix* properties screen, click on the *Asphalt Binder* tab and select Superpave binder grade 64-22 as shown in Figure D. 150.

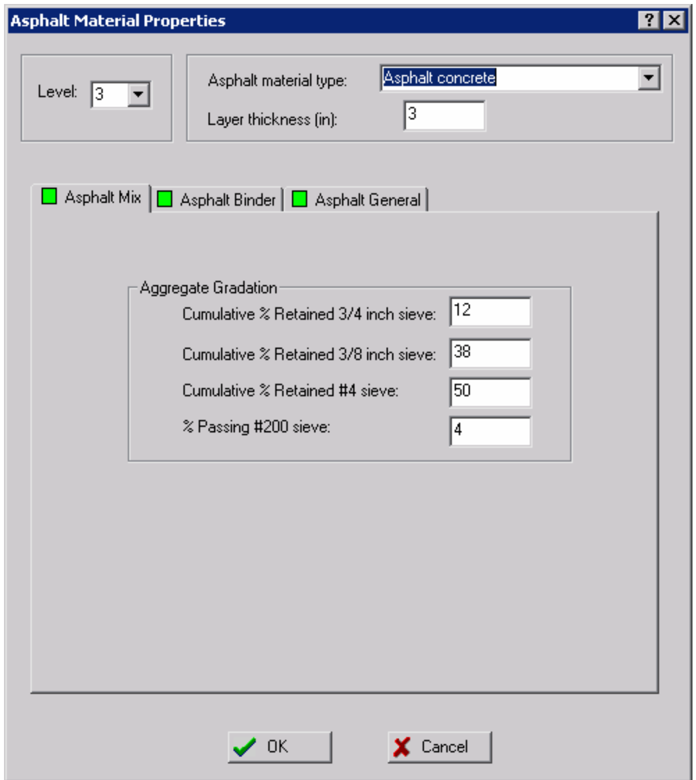


Figure D. 149. *Asphalt Material Properties* screen – *Asphalt Mix* property page.

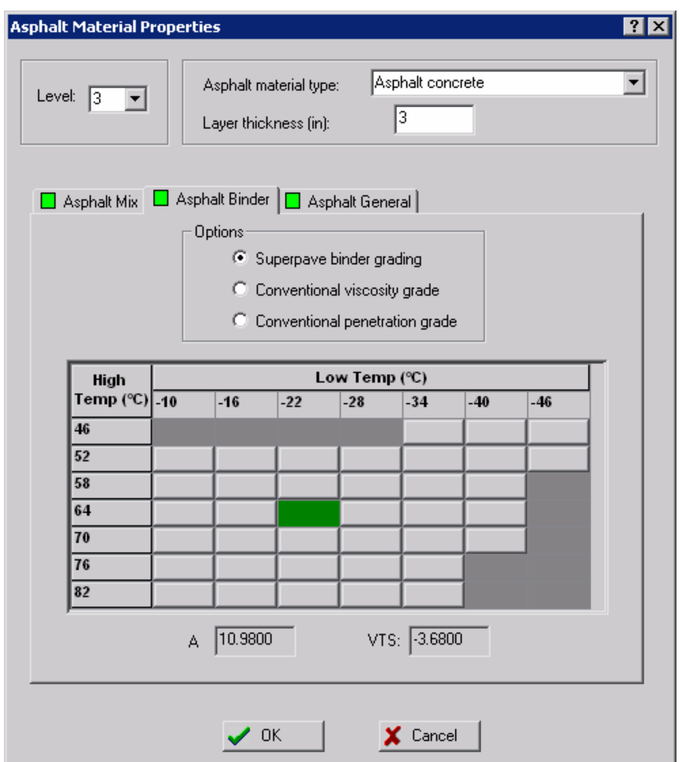


Figure D. 150. *Asphalt Material Properties* screen – *Asphalt Binder* property page.

Next, click on the *Asphalt General* tab and make the following inputs for this example as shown in Figure D. 151:

General
- Reference temperature (F°): 70

Volumetric Properties
- Effective binder content (%): 12
- Air voids (%): 6.0
- Total unit weight (pcf): 143

Poisson's ratio: 0.35 (user entered)

Thermal Properties
- Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
- Heat capacity asphalt (BTU/lb-F°): 0.23

Click *Ok* and return to the main program layout screen. Note that the icon adjacent to *Layer 1 – Asphalt concrete* layer is now green in color because of inputs being complete in this layer.

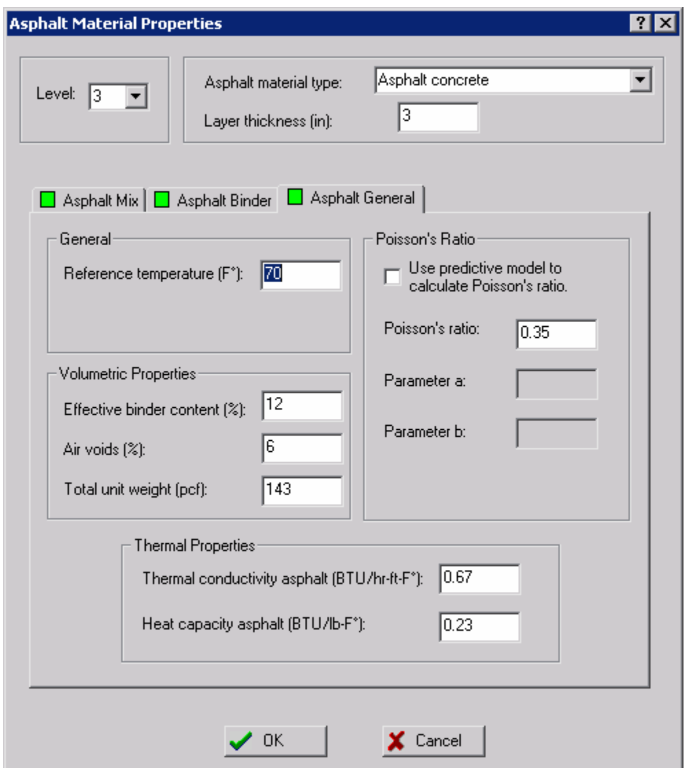


Figure D. 151. *Asphalt Material Properties – Asphalt General* screen.

<u>D.5.5.2.2 *Layer 2 – A-1-a*</u>

Click on *Layer 2 – A-1-a* on the program layout screen to enter base layer material inputs. The screen that enables the user to make inputs for an unbound layer opens as shown in Figure D. 152.

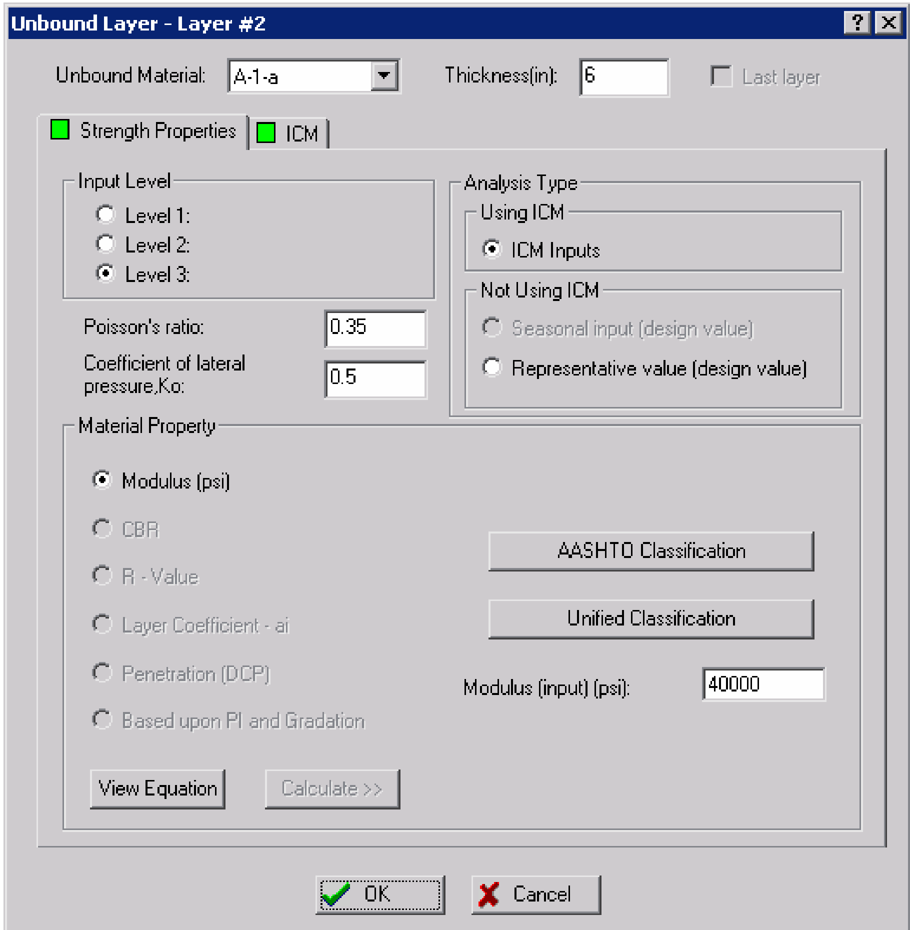


Figure D. 152. *Base (Unbound) layer* screen – *Strength Properties* page.

Note that the choice made for the unbound material type and the layer thickness appear on the screen. (This screen also allows the user to make changes to previous choices if necessary).

Choose the radio button corresponding to level 3 inputs, which requires only the input for modulus for material property. Enter the following input values:

Poisson's ratio: 0.35
Coefficient of lateral pressure: 0.50
Modulus (psi): 40,000

For *Analysis Type*, click on the radio button adjacent to *ICM Inputs* to indicate that the user will make ICM inputs to the program

Next, click on the ICM tab to make ICM inputs. The inputs made on this screen, shown in Figure D. 153, are as follows:

Plasticity Index, PI: 1
Passing #200 sieve (%): 3
Passing #4 sieve (%): 20
D60 (mm): 8

The granular base layer will be a compacted subgrade layer and hence click on the radio button corresponding to *Compacted unbound material*. Click on *Update* to view the various parameters that are calculated or derived by ICM.

Click *OK* and return to the main program layout screen.

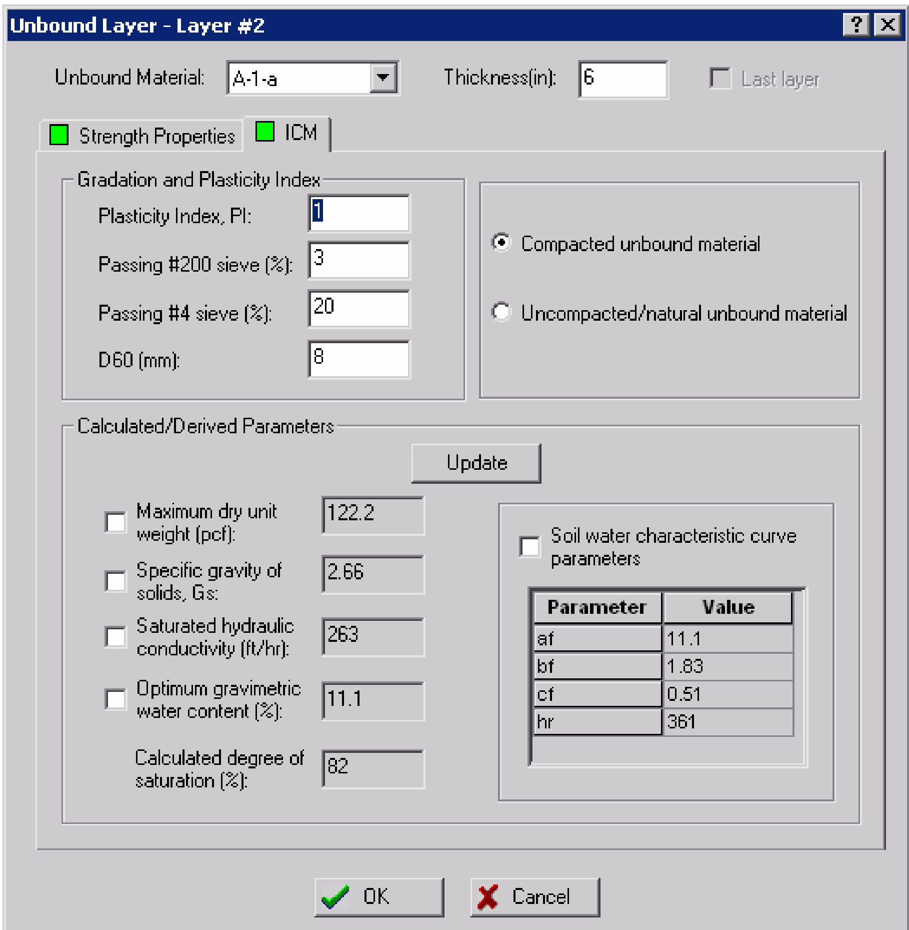


Figure D. 153. *Base (Unbound) layer* screen – *ICM* property page.

<u>D.5.5.2.3 *Layer 3 – A-2-5*</u>

Layer 3 is the subbase layer which is also an unbound layer similar to layer 2. Repeat the steps followed in 5.5.2.2 and enter the specified inputs as shown in Figure D. 154 and Figure D. 155.

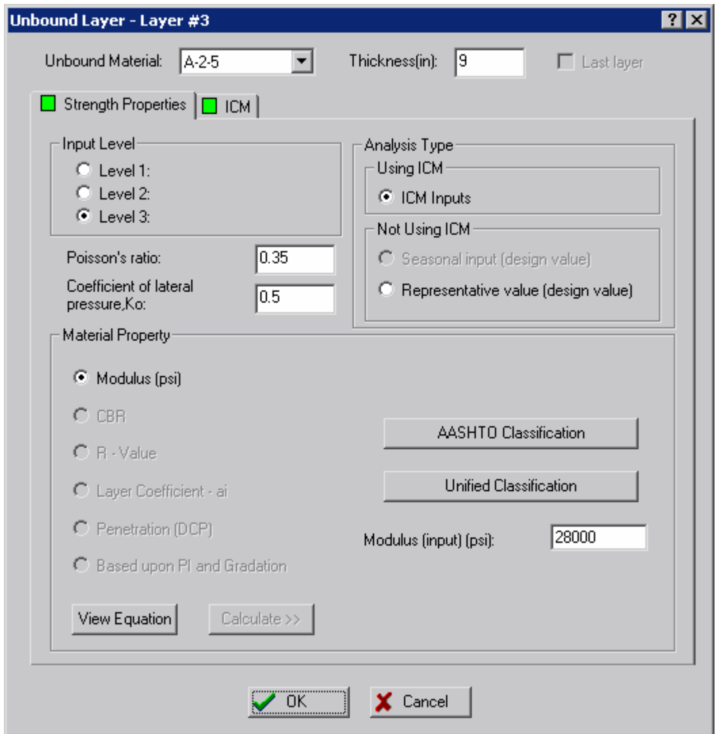


Figure D. 154. Subbase *(Unbound) layer* screen – *Strength Properties* page.

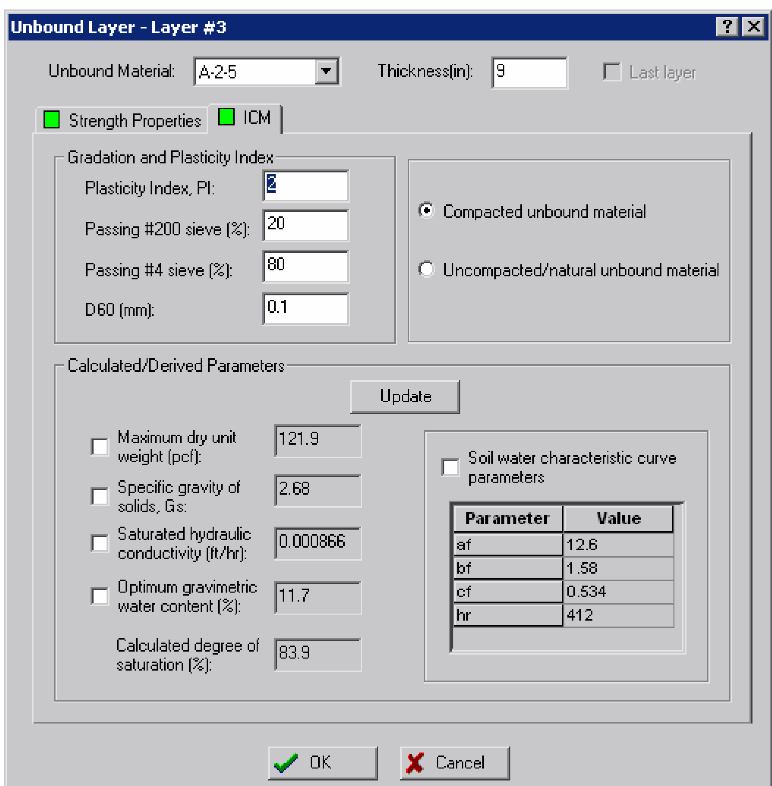


Figure D. 155. Subbase *(Unbound) layer* screen – *ICM* property page.

D.5.5.2.4 *Layer 4 – A-7-6*

The fourth layer in this trial design is the natural subgrade classified as AASHTO soil A-7-6. The inputs made for the subgrade layer are identical in nature to the input provided for the unbound base and subbase materials. The inputs are shown in Figure D. 156 and Figure D. 157. Note that on the ICM property page, click on the radio button corresponding to *Uncompacted/natural unbound material* as shown in Figure D. 157.

Click on *Update* and view the ICM calculated parameters. Next, click *Ok* and return to the program layout screen.

D.5.5.3 *Thermal Cracking*

This screen provides an interface to provide all inputs required to predict thermal cracking The software program uses the tensile strength, creep compliance, coefficient of thermal contraction, surface shortwave absorptivity, thermal capacity and heat capacity to predict thermal cracking. These inputs can all be either user input, or the software uses default values that are calculated from the asphalt material properties entered for the first asphalt layer in the pavement structure (see 2.2.2.4). Note that if the user attempts to make inputs to the *Thermal Cracking* screen before the material inputs are finalized for the first AC layer, the program prompts the user to visit the material properties screen first. For the purpose of this design example, click on the radio button for Level 3 inputs and view the default inputs for the chosen material as shown in Figure D. 158.

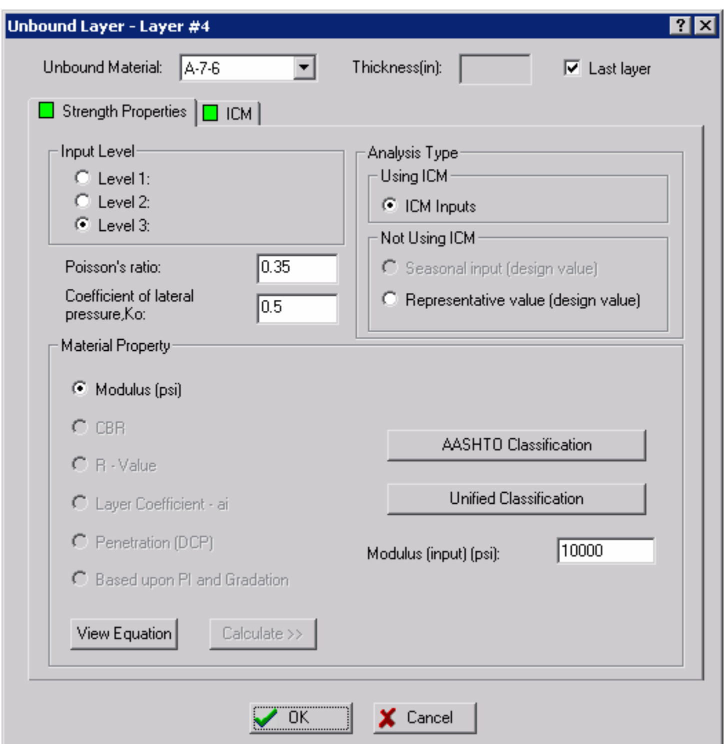


Figure D. 156. *Unbound layer* screen for natural subgrade layer.

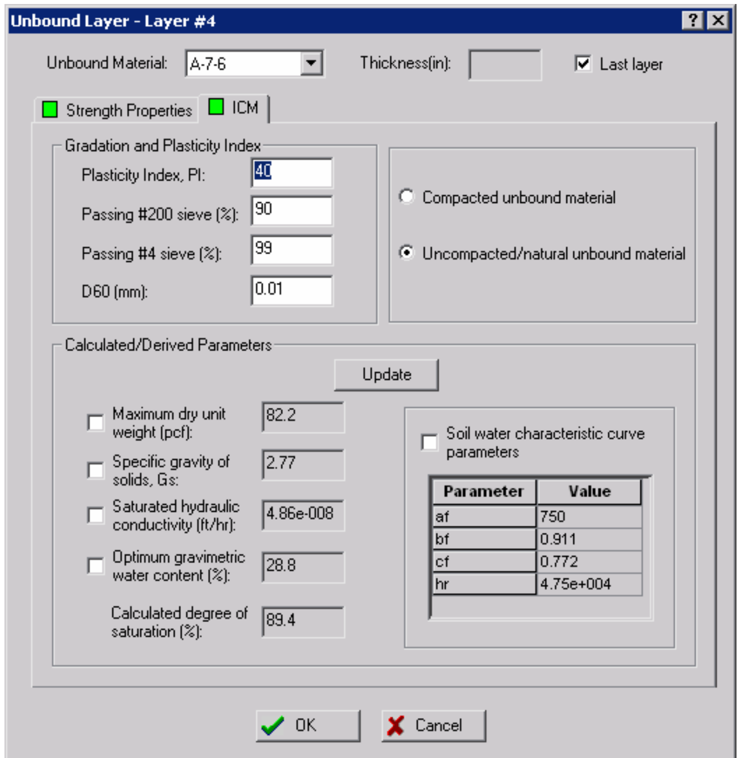


Figure D. 157. Subbase *(Unbound) layer* screen – *ICM* property page.

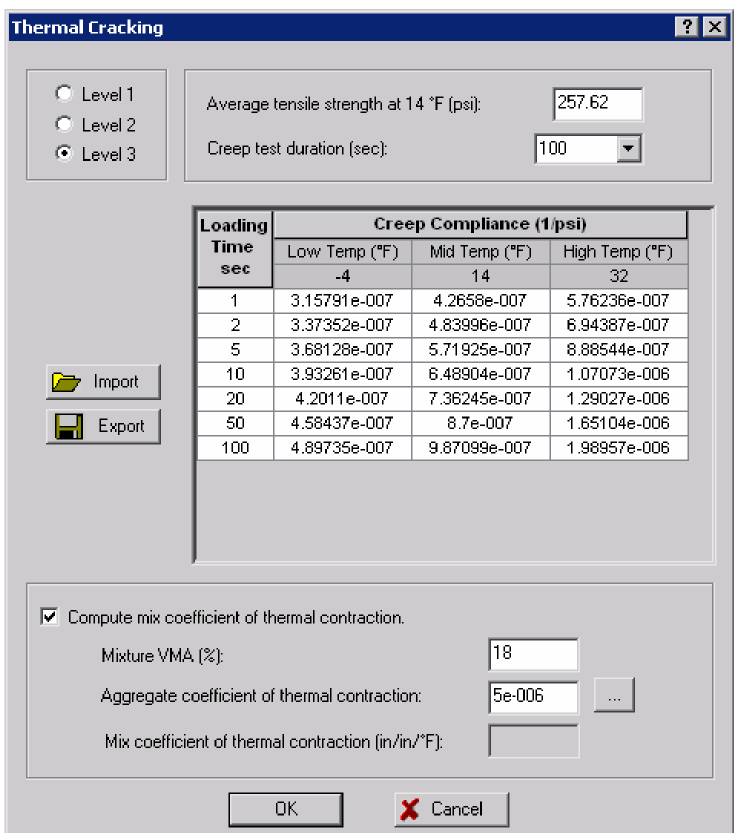


Figure D. 158. *Thermal Cracking* screen.

Note that on this screen, the user has the option of *importing* a previously saved creep compliance dataset, or *exporting* the currently dataset to a file for later use. Also, the *Mix Coefficient of Thermal Expansion*, can either be either computed using default correlations, as was done in this example, or can be a user input value.

Click *Ok* and return to the mail program layout screen. Establishment

D.5.6 Distress Potential

Next, click on the *Distress Potential* item and enter "*None*" for both block cracking and sealed longitudinal cracks outside of wheelpath as shown in Figure D. 159.

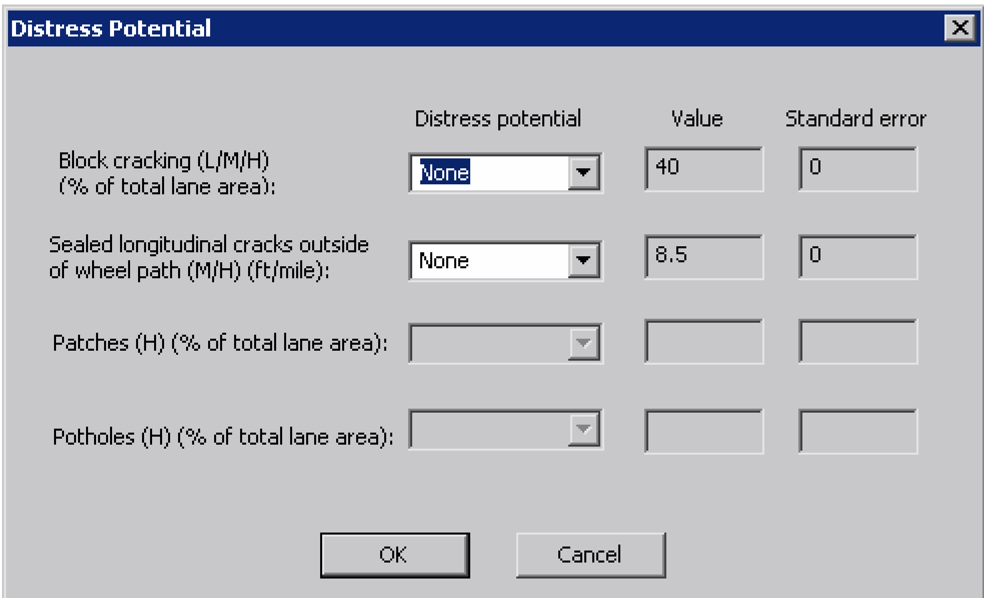


Figure D. 159. Distress potential.

Click *Ok* and return to the main program layout screen as shown in Figure D. 160. Note that in Figure D. 160, the icons adjacent to all inputs – traffic, climate, and structure – are green indicating that all these inputs are complete.

D.5.7 Run Analysis

After all design inputs are provided, the Design Guide software has to begin the analysis process to predict the performance of the trial design over the design life of the pavement. Click on *Run Analysis*. The program runs the Traffic, Climate, Modulus, Thermal cracking, AC analysis modules, and reports the analysis status on the upper right hand corner of the screen.

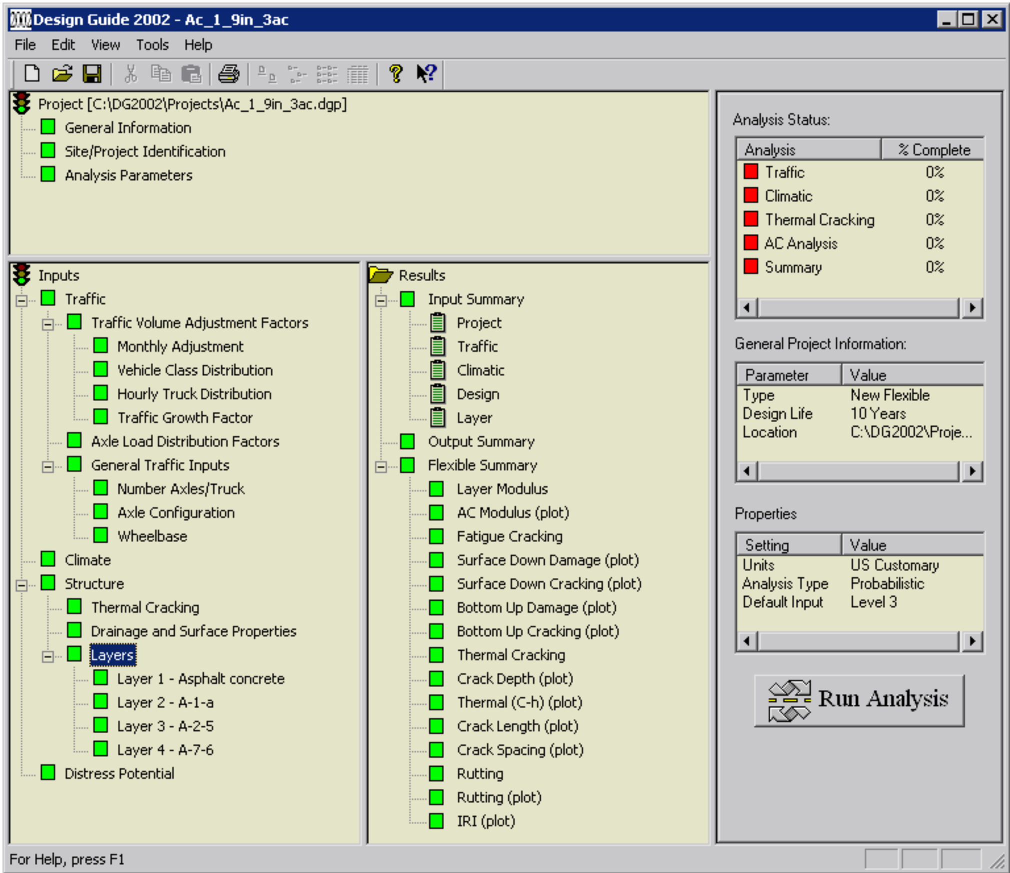


Figure D. 160. Program layout screen after completing all inputs.

At the end of the analysis, the program creates a summary file and other output files in the project directory, *C:\DG2002\Projects\AC Conventional Example*. The summary file is in an MS Excel format and is named "*AC Conventional Example.xls*." The summary file contains an input summary sheet, computed material modulus values, and distress summaries for all predicted distresses in a tabular format. Further, the predicted distresses and IRI over time are also represented in a graphical format.

The AC modulus predicted by the program for the given climate and subgrade moisture conditions is shown in Figure D. 161. These modulus values are also reported in a data sheet titled *Layers Modulus*. The performance of the trial design over the specified design life is also plotted in the output file as shown in Figure D. 162 through Figure D. 166 for top-down longitudinal cracking, alligator cracking, thermal cracking, rutting and IRI respectively. The output file has accompanying data sheets for all these charts, as well as charts illustrating damage accumulation for each distress.

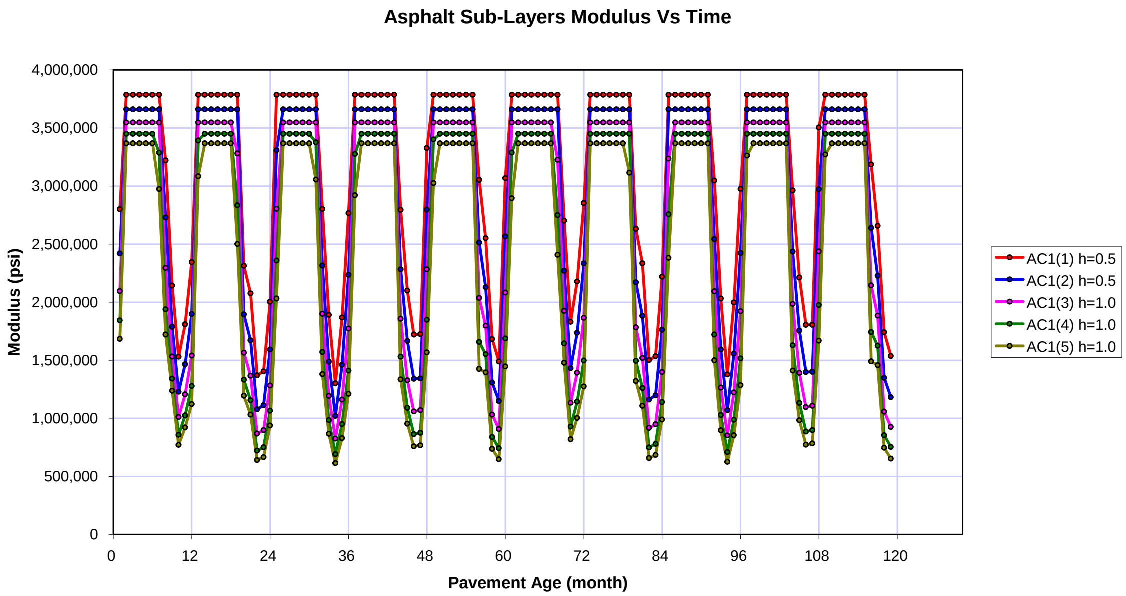


Figure D. 161. Trial design AC modulus predicted by the Design Guide program.

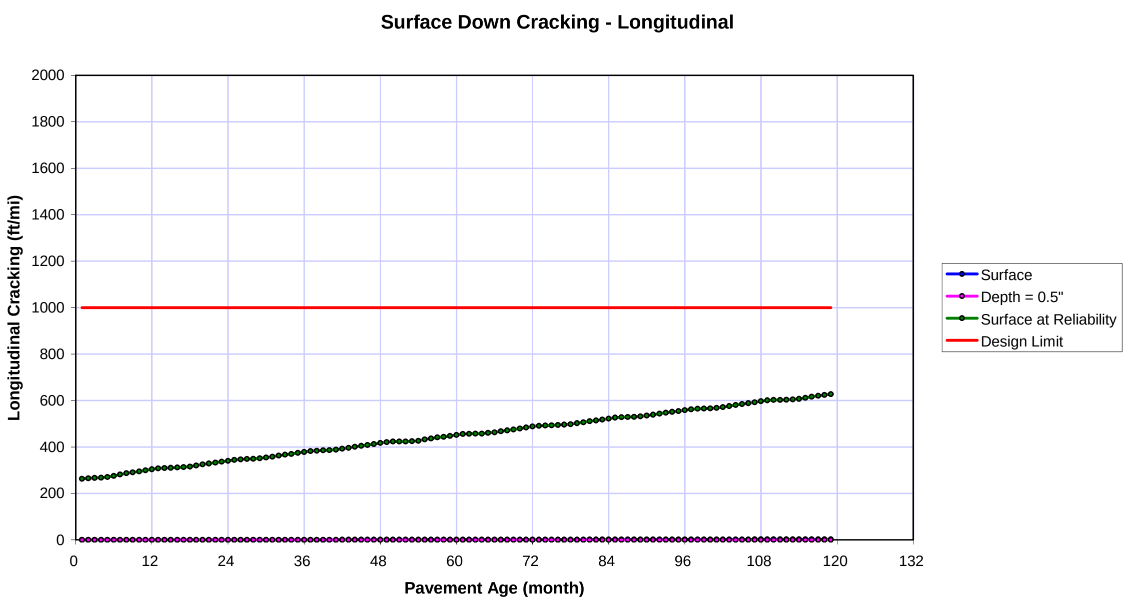


Figure D. 162. Surface down longitudinal cracking.

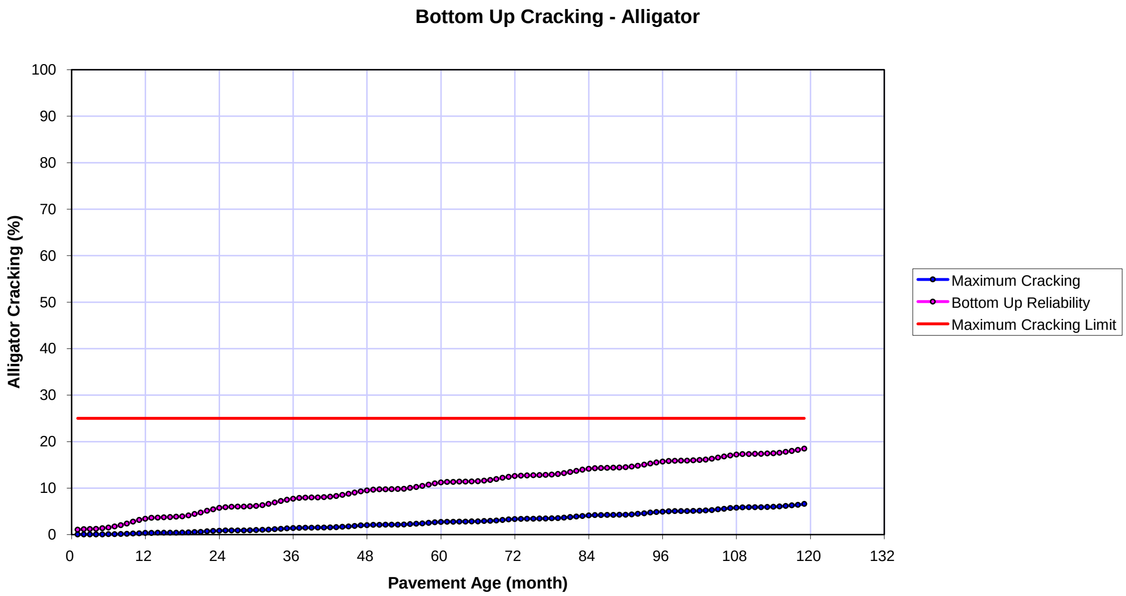


Figure D. 163. Alligator cracking prediction over design life for the trial design.

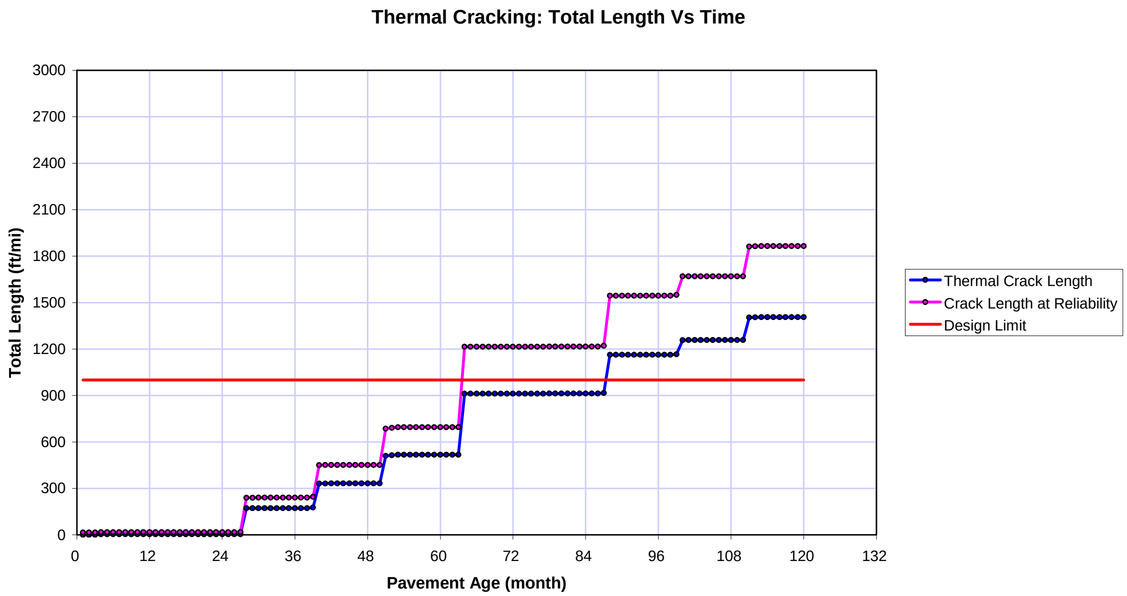


Figure D. 164. Thermal cracking prediction over design life for the trial design.

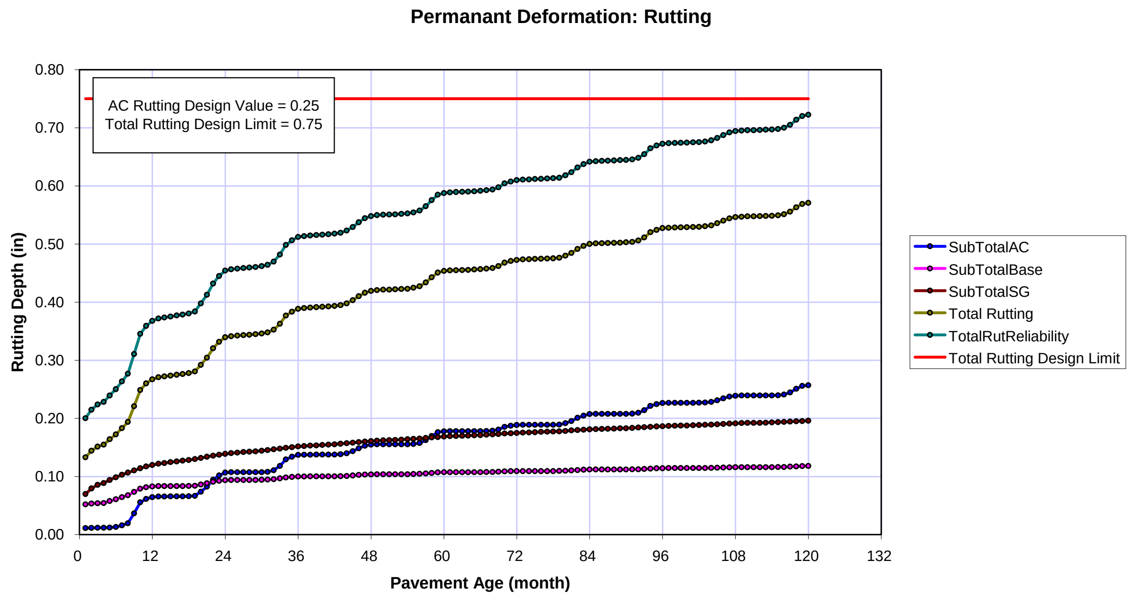


Figure D. 165. Rutting prediction over design life for the trial design.

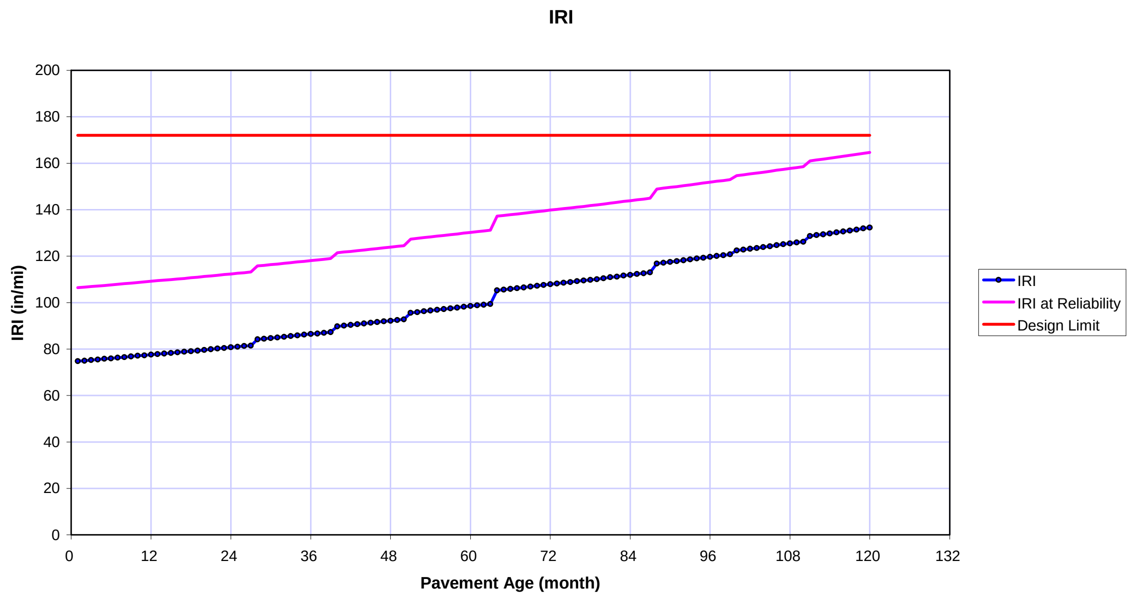


Figure D. 166. Predicted IRI over design life for trial design.

D.5.8 Sensitivity Analysis

The trial design satisfies the design criteria specified in the program for all analysis parameters except thermal cracking requirement (Figure D. 164). AC rutting Figure D. 165. Therefore, this trial design cannot serve as a feasible design. Note that thermal cracking is a temperature related distress and can be less controlled with changes to the structural capacity of the pavement. For example, increasing or decreasing the subbase layer, although would affect cracking and rutting predictions as shown in the sensitivity analysis presented in Figure D. 167, Figure D. 168, and Figure D. 169. The thermal cracking prediction, shown in Figure D. 170, is less sensitive to the structural design, and more a function of the binder grade selected. However, note that substantial increase in the thickness of the subbase (i.e. from 9 in to 18 in) will alter the moisture profile predicted by the EICM module and can result in significant changes to the thermal cracking prediction. Note that there is no subbase thickness value that satisfies the thermal cracking requirement in this design. Also, changing the subbase thickness does not alter the AC rutting values significantly as shown in Figure D. 171.

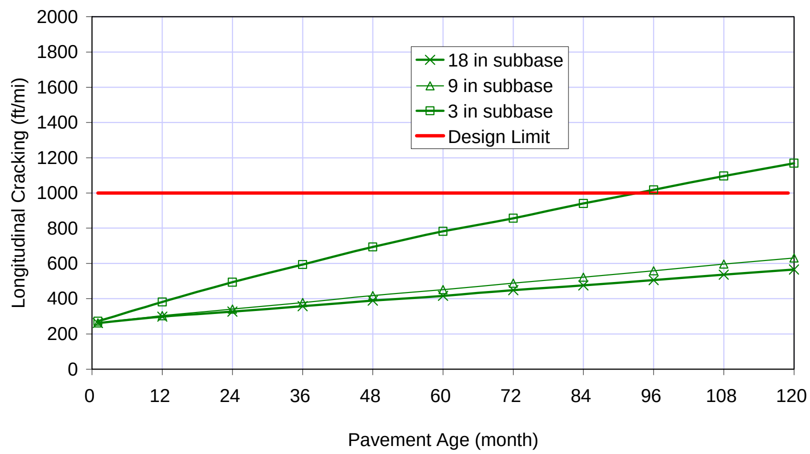


Figure D. 167. Sensitivity of surface-down cracking to subbase thickness.

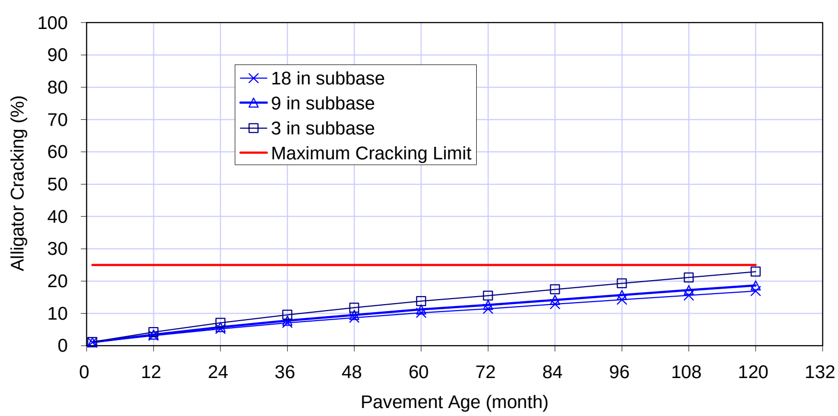


Figure D. 168. Sensitivity of bottom up fatigue cracking to subbase thickness.

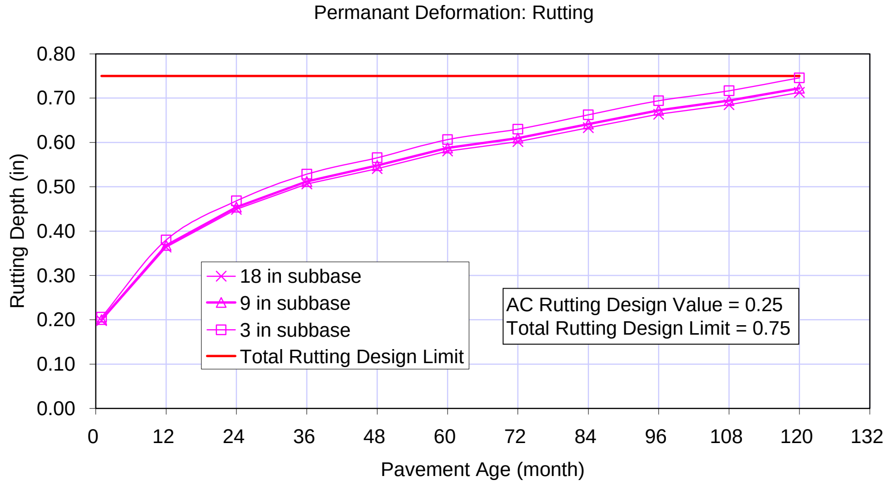


Figure D. 169. Sensitivity of total rutting to subbase thickness.

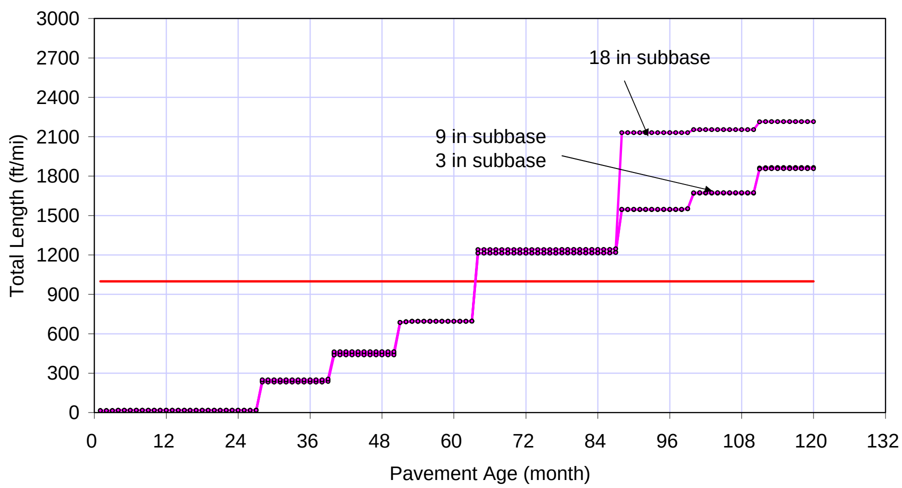


Figure D. 170. Sensitivity of thermal cracking prediction to subbase thickness.

D.5.9 Modify Trial Design

The design can be modified by altering the PG grade of the binder used in the mix design. For example, use a 64-28 Superpave PG-grade for the asphalt binder with subbase thickness of 18 inches to improve the thermal cracking and rutting performance. The thermal cracking and rutting performance for the modified design are shown in Figure D. 172 and Figure D. 173.

It is recommended that the designer verify other alternatives by means of a sensitivity analysis in order to develop the most optimum design. Sensitivity charts are provided in this User's Guide to demonstrate the effect of some design inputs to performance prediction (subbase thickness in this case). The user is urged to verify several modifications to the initial trial design to reach an optimum design.

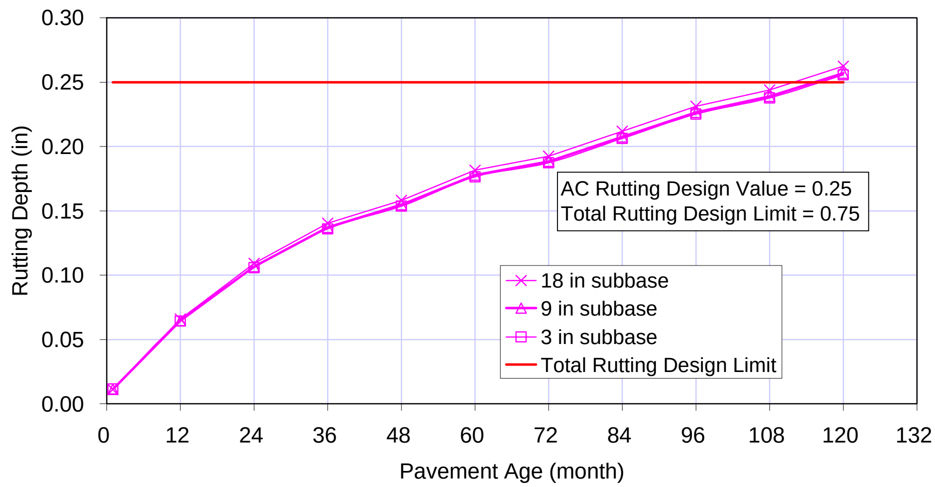


Figure D. 171. Rutting in AC layer with changing subbase thickness.

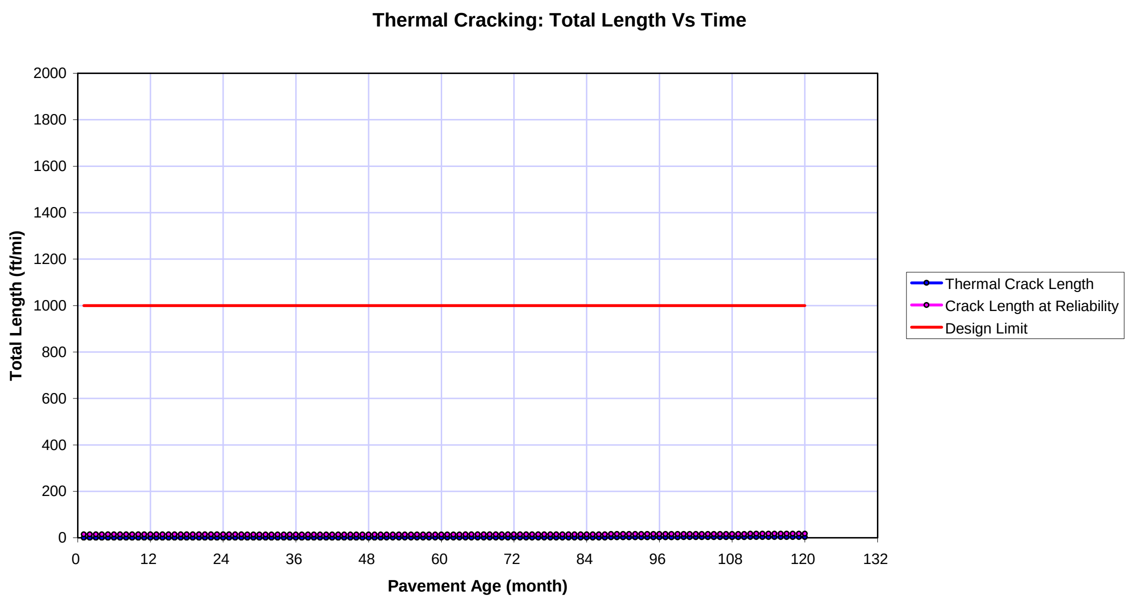


Figure D. 172. Thermal cracking prediction for the modified design (64-28 PG binder and 18 inch subbase thickness).

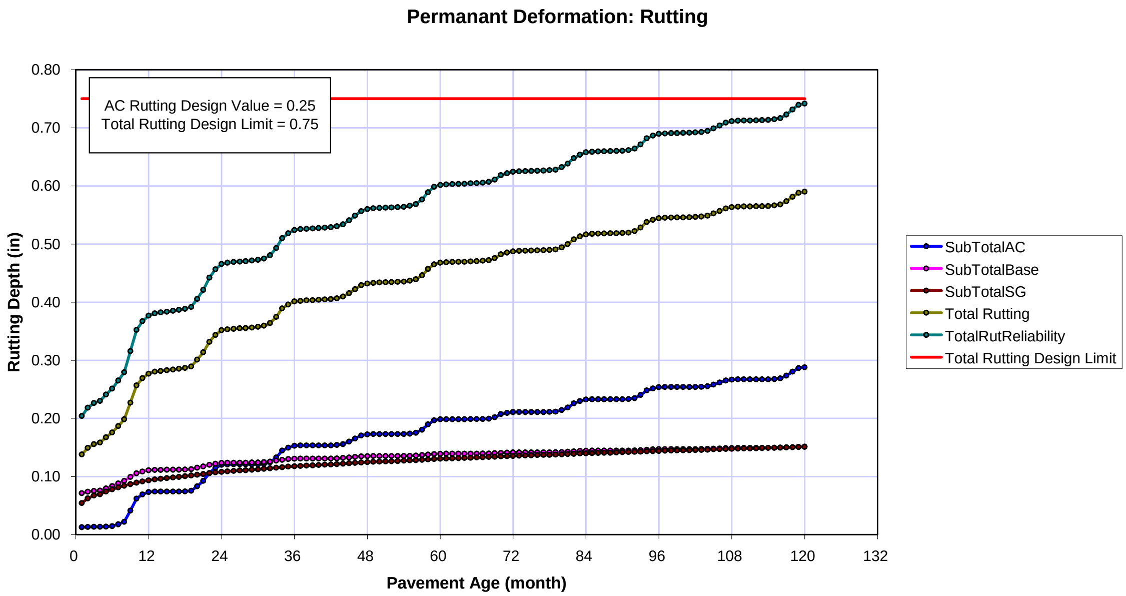


Figure D. 173. Predicted rutting for modified design (64-28 PG binder and 18 inch subbase thickness).

D.6 AC OVER EXISTING AC REHABILITATION DESIGN EXAMPLE

It is expected that, prior to performing AC rehabilitation design, the user is familiar with the use of the design software for the design of new AC sections (explained in detail in Section D.5). The problem statement for these rehabilitation options covers all information required for making design inputs to the software. Unlike the design examples for new flexible pavements in Section D.5, this example does not contain screen shots for all design inputs. It is expected that with the experience of performing a new pavement design, the user will be able to make all inputs for the traffic, climate, and structural inputs for the existing pavements. However, appropriate screen shots of the design software that are different from the new design, or those that are typical to rehabilitation design, are provided to guide the user with the design procedure. Users are urged to refer to Section D.5 where necessary.

D.6.1 Problem Statement for AC Rehabilitation

Summarized in Table D.6.1 are the climate, material properties, structure, and design features of the existing AC pavement. The information presented was obtained from a comprehensive evaluation of the conventional flexible pavement using procedures presented in PART 2, Chapter 5 of this Guide. The AC pavement was constructed in August 1980 and is located in Columbus, Ohio. The ground water table is 10 feet deep at the project location. Using the data presented in Table D.6.1 as the basis, consider an AC overlay option.

Table D.6.1. Material properties of existing AC pavement.

Layer Number	**Variable**	**Value**
Existing Layer 1 (Considered as Layer 2 in overlay analysis)	Material type	AC (existing)
	Layer thickness (in)	7
	Mix - Cumulative retained on ¾” sieve (%)	0
	Mix - Cumulative retained on $^{3}/_{8}$” sieve (%)	5
	Mix - Cumulative retained on #4 sieve (%)	40
	Mix - Passing #4 sieve (%)	4
	Backcalculated modulus in psi (at 30hz, 70deg F)	1,000,000
	Binder viscosity grade	AC-20
	Volumetrics - Mix binder content (%)	11
	Volumetrics - Air void (%)	8.5
	Total unit weight (pcf)	145
	Thermal conductivity (BTU/hr-ft-F°)	0.67
	Heat capacity (BTU/lb-F°)	0.23
Existing Layer 2 (Considered as Layer 3 in overlay analysis)	Material type	Crushed Stone
	Thickness, in	12
	Poisson's ratio	0.35
	Coefficient of lateral pressure, Ko	0.5
	Modulus, psi	35000 from FWD analysis (Level 1)
	Plasticity Index, PI	1
	Passing No. 200 sieve, percent	6.2
	Passing No. 4 sieve, percent	54
	D60, mm	6
Layer 3	Material type	SC
	Thickness, in	Semi-infinite
	Poisson's ratio	0.35
	Coefficient of lateral pressure, Ko	0.50
	Modulus, psi	24000 from FWD analysis (Level 1)
	Plasticity Index, PI	15
	Passing No. 200 sieve, percent	25
	Passing No. 4 sieve, percent	90
	D60 (mm):	0.1
Distress Potential	Sealed longitudinal cracks outside of wheel path	None
	Patches	None
	Potholes (%):	None

This example constitutes a level 1 rehabilitation design. If a level 3 rehabilitation design is used, the design procedure will require the pavement rating (excellent through very poor) as an input, some of which will be illustrated during the course of this example.

Design Life

The expected construction date of the rehabilitation alternative is September 2002, and the rehabilitated pavement must be opened to traffic in October 2002. Assume a design life of 20 years for the AC over AC option.

Construction Requirements

Assuming a good quality of construction, the pavement shall have an initial IRI between 50 and 75 in/mile (assume 63 in/mile for design purposes).

Analysis Parameters

It is expected that, at the end of the 10-year design life, the pavement will have no more than an IRI of 172 in/mile, AC surface-down or longitudinal cracking of 1000 ft/mile, bottom-up fatigue cracking of 25 percent, and AC thermal fracture (transverse cracking) of 1000 feet per mile. The permanent deformation in the AC layer shall not exceed 0.25 inches, and that in the total pavement shall not exceed 0.75 inches. In addition, if a chemically stabilized layer is used, the fatigue fracture in the layer shall not exceed 25 percent. These criteria are to be satisfied at a reliability level of 90 percent.

Traffic

Future traffic estimates for rehabilitation design are as follows:

- Two-way average annual daily truck traffic: 200
- Number of lanes in design direction: 2
- Percent of trucks in design direction: 50 percent
- Percent of trucks in design lane: 95 percent
- Operational speed: 60 mph
- Traffic growth rate design life: 4 percent
- Traffic growth function: Compound

This pavement is categorized as a principal arterial/interstate highway, and the section carries less than 2 percent buses but greater than 10 percent multi-trailers. The traffic characteristics developed using information from past traffic data collected show the percentage of AADTT in each vehicle class is closest to the default TTC#1 in the Design Guide software.

For each class of vehicle, the traffic pattern on monthly and daily bases remains the same through out the year. However, the traffic varies over a 24-hour period and is the same as the national default based on LTPP data (provided in the Design Guide and the software).

The axle load distribution is identical to the LTPP default distribution for each vehicle class, axle type, load category, and months of the year; hence, the number of single, tandem, tridem, and quad axles is same as the national defaults provided in the Design Guide software.

Assume that, for all vehicle classes and axle wheel types, the left and right wheels are located 18 in from the centerline joint and the slab–shoulder joint, respectively. The traffic wander has a standard deviation of 10 inches from the wheels mean location. The axle configuration is as follows:

- Average axle width (edge-to-edge outside dimensions, ft): 8.5
- Dual tire spacing (in): 12

The single and dual tire pressures are 120 psi. The design lane is 12 feet wide. The average axle spacing for tandem, tridem and quad axles are as follows:

- Tandem: 51.6 in
- Tridem: 49.2 in
- Quad: 49.2 in

D.6.2 Trial Design

D.6.2.1 Create a New Project

Create a rehabilitation design project in the Design Guide program
Open the Design Guide program from the *Programs* menu of the operating system (Windows 98, 2000, XP, NT). Next, open a new file and assign a name to the project, "*AC_on_AC*," as shown in Figure D.174. Next, select the folder to store the design files as "*C:\DG2002\Projects.*" Select US Customary units as the measurement system by clicking the radio button adjacent to it. Next, click "*OK*" to open the main layout screen of the design project.

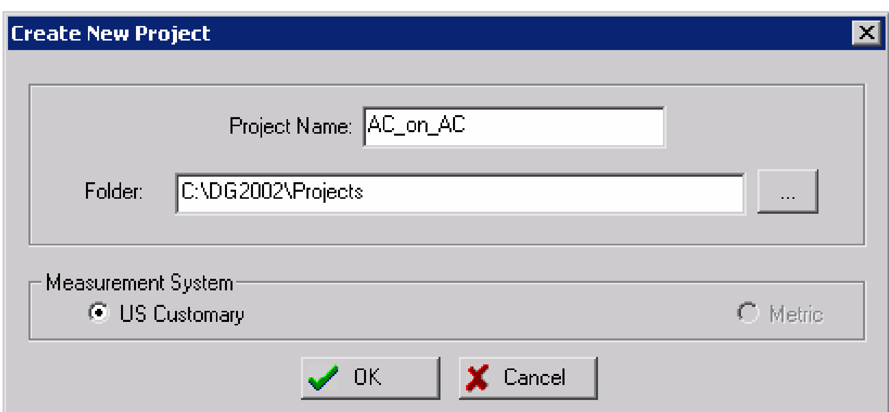


Figure D.174. Create a new project file from the main program.

D.6.2.2 Enter General Inputs

On the main project screen, click on the *General Information* input to open the *General Information* screen. Enter inputs on the General Information Screen as shown in Figure D.175. Click *OK* and return to the program layout screen.

D.6.2.3 Enter Inputs on the Site/Project Identification Screen

Click on *Site/Project Identification* to open the *Site/Project Identification* screen. The inputs procedure for this design is same as for new design.

D.6.2.4 Enter Inputs on the Analysis Parameters Screen

Enter the analysis criteria for the AC section after rehabilitation as shown in Figure D.176.

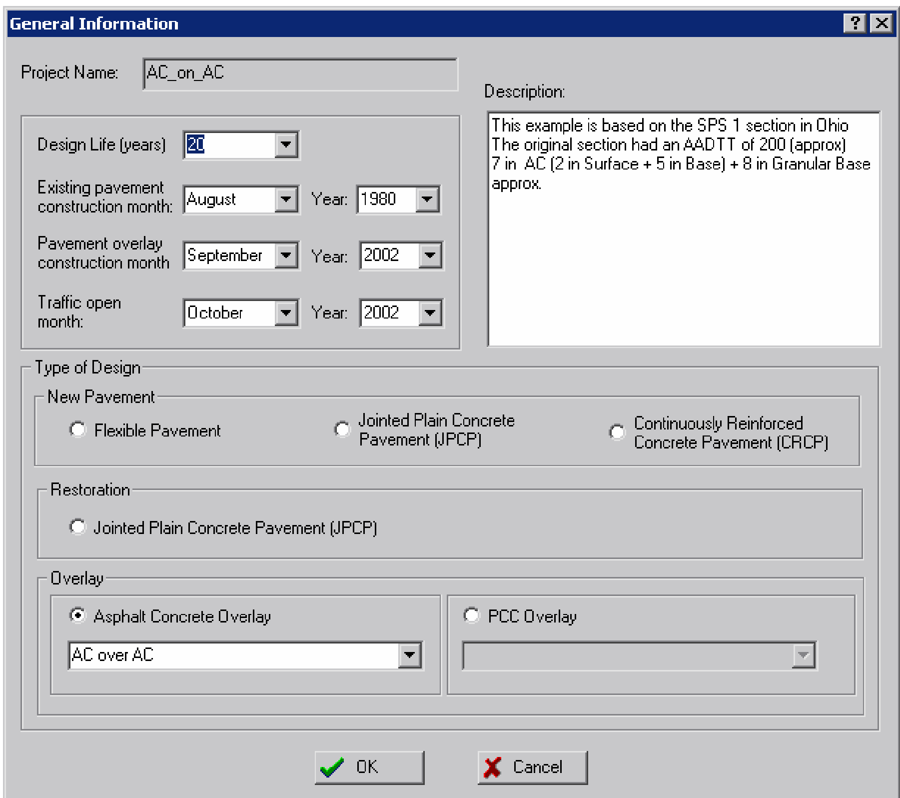


Figure D.175. *General Information* screen.

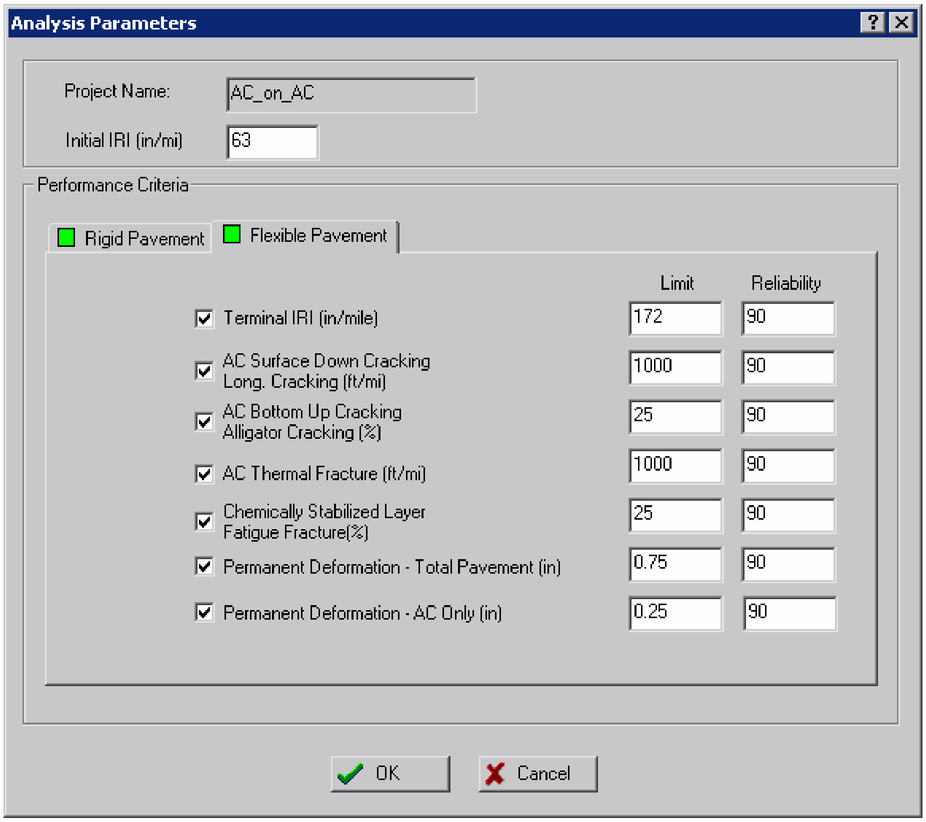


Figure D.176. *Analysis Parameters* screen for AC on AC overlay.

D.6.2.5 Traffic Inputs

Traffic inputs are the same as for new design. Follow the step-by-step procedure provided in Section D.5.3. Note that actual inputs required for this design are presented in the problem statement.

D.6.2.6 Climate Inputs

Climate inputs are the same as for new design. Follow the step-by-step procedure provided for new AC design. Note that actual inputs required for this design are presented in the problem statement. Use the climatic file for Columbus, Ohio, and use a water table depth of 10 feet. The user then returns to the main program layout screen as shown in Figure D. 177.

The user is now ready to provide inputs for the structural and material properties. Note that the program has automatically inserted the two obvious layers to the pavement structure, the existing AC layer and the new AC overlay.

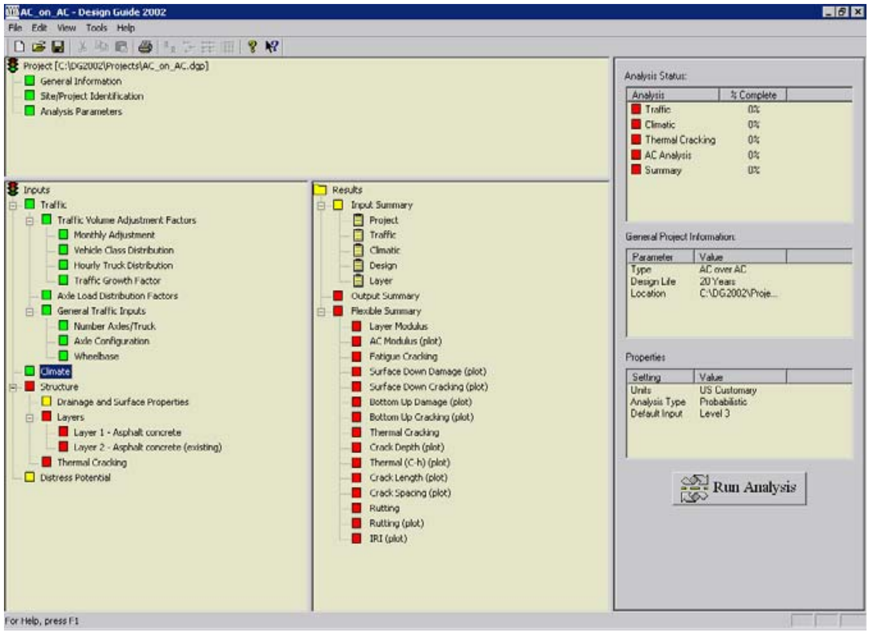


Figure D. 177. Program layout screen after making general, traffic, and climate inputs.

D.6.2.7 Structural Inputs

The structural inputs for an AC overlay design are similar to the structural inputs for a new design (see Section D.5) and essentially fall under the following three categories:

- Drainage and surface properties.
- Layers.
- Thermal cracking.

The thermal cracking and drainage inputs are the same as those discussed in Sections D.5.5.1 and D.5.5.3. Note that the *Thermal Cracking* screen has to be visited after the layer properties are input in the *Layers* screens.

Layers - Defining Pavement Structure

In the layers section, the program creates two AC layers by default, as the chosen rehabilitation type is *AC over AC*. The user then needs to add the existing layers underneath the existing AC layer using the procedure described in Section D.3.5.3 to result in a *Layers* screen, as shown in Figure D. 178.

Choose a pavement rating of “Excellent” and a rutting value of “0.” The milled thickness is 1 inch.

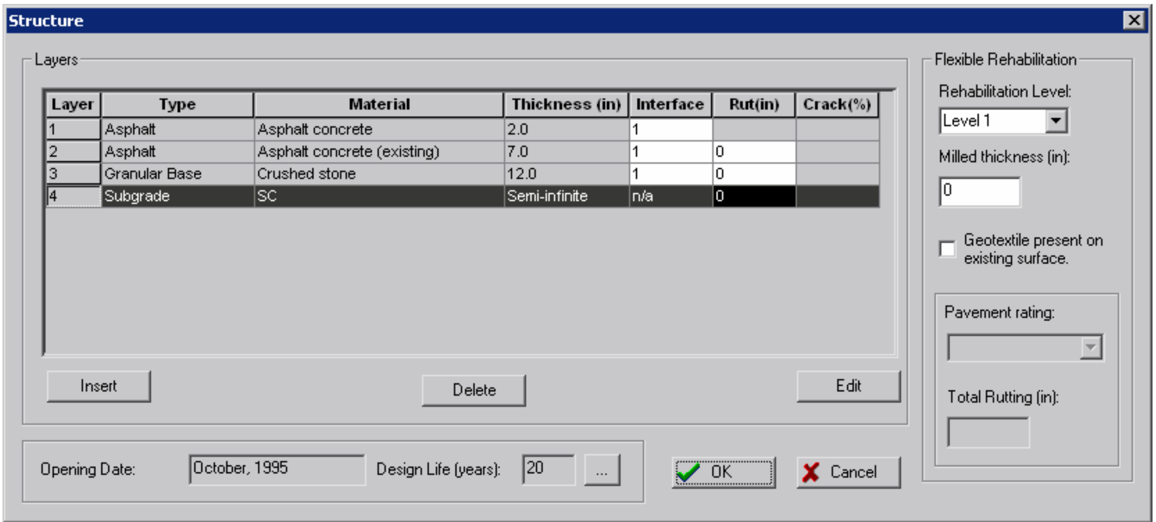


Figure D. 178. *Layers* screen after the addition of all existing layers beneath the new AC overlay.

The pavement structure consisted of four layers, including the subgrade and the new AC overlay, and the layer properties as required by the Design Guide program are presented in Table D.6.1. Information required for each material property is typically obtained from various source including field-testing, laboratory analysis, and agency records, as discussed in PART 2, Chapter 5.

Also, choose *Level 1* from the pull down menu of the *Flexible Rehabilitation* section to select the hierarchical level being used for the rehabilitation. Enter a value of zero for the milled thickness to indicate that the existing pavement is not being milled. Also note that a rutting value of zero inches is being used for all existing layers to indicate the rutting condition of the existing pavement.

If the user chooses to use a Level 3 rehabilitation, the user needs to indicate the *Pavement Rating* for the existing pavement to indicate the condition of the existing pavement. The *Total Rutting* is the rutting observed in the pavement after the pavement has been milled. Note that Level 3 rehabilitation is not being considered in this example. However, given the frequent use of this design type, this information has been provided in the User's Guide.

Input *Layer* Properties

Next, after defining the pavement structure, input material and structural properties for all layers following the same procedure described for new AC design in Section D.5.5.3. For the new AC layer assume 0, 5,and 40 percent are retained on the ¾", $^3/_8$" and #4 sieves, while 4 percent passes the #200 sieve. Use an AC-20 conventional binder type. The volumetric properties of the new AC layer are same as those of the existing AC layer. Finally, the thickness of the new AC overlay is 2 inches. The inputs made for the AC layer are shown in Figure D. 179 and Figure D. 181.

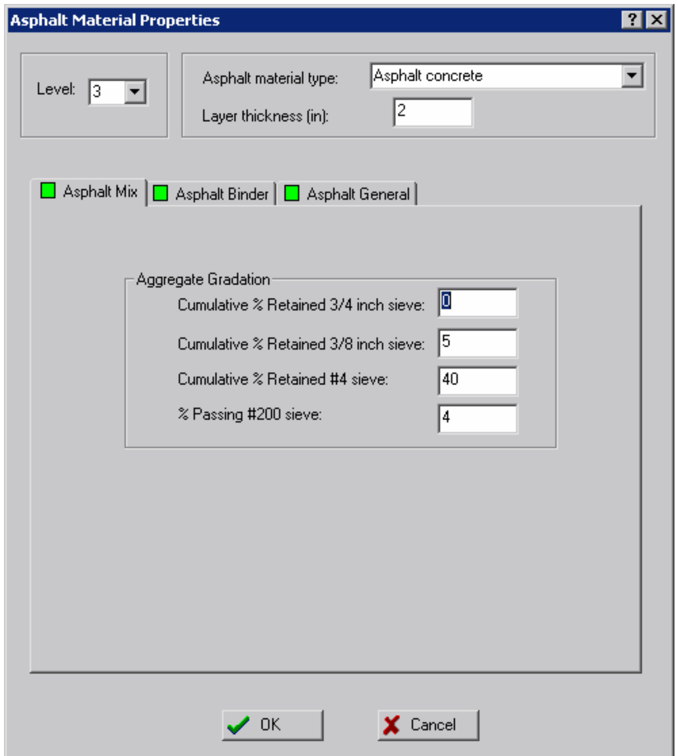


Figure D. 179. AC overlay material properties – *Asphalt Mix.*

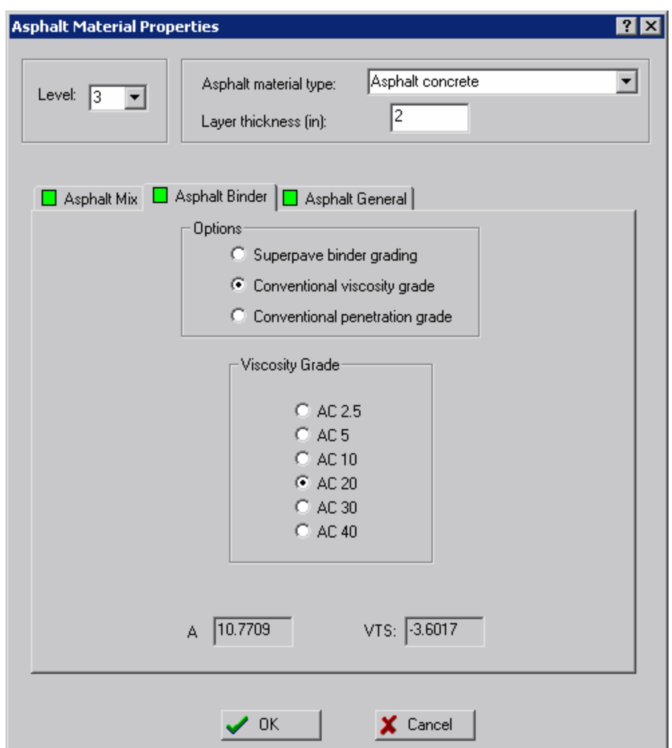


Figure D. 180. AC overlay material properties – *Binder Properties.*

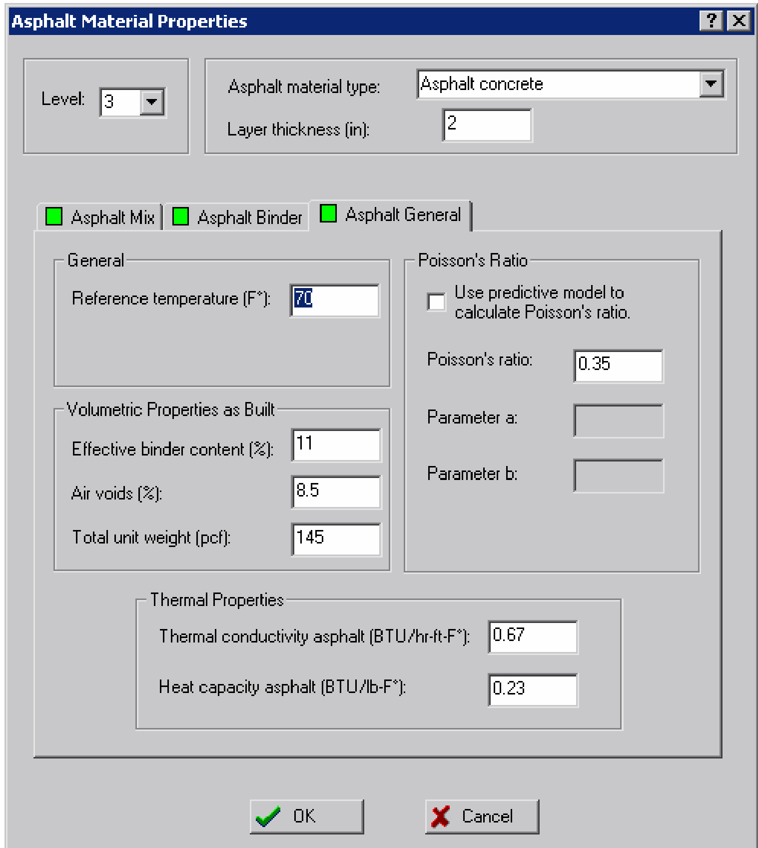


Figure D. 181. AC overlay material properties – *Asphalt General and Volumetrics.*

Next, for the existing AC layer, input material properties as shown in Figure D. 182, Figure D. 183, and Figure D. 184. For level 1 rehabilitation design, the backcalculated moduli from Falling Weight Deflectometer (FWD) tests are input for the modulus values for all layers of the existing pavement. As shown in Figure D. 182, enter the backcalculated modulus value of 1,000,000 psi, frequency of 30 Hz, and temperature of 70 deg F.

Visit the *Thermal Cracking* screen and accept the default values generated by the program for the given asphalt concrete material inputs.

D.6.2.8 Distress Potential

Next, click on the Distress Potential icon from the main project layout screen and enter the distress potential based on the information provided in Table D.6.1, as shown in Figure D. 185.

Click *OK* and return to the main project layout screen, and as shown in Figure D. 186, the color scheme indicates that all required inputs have been provided.

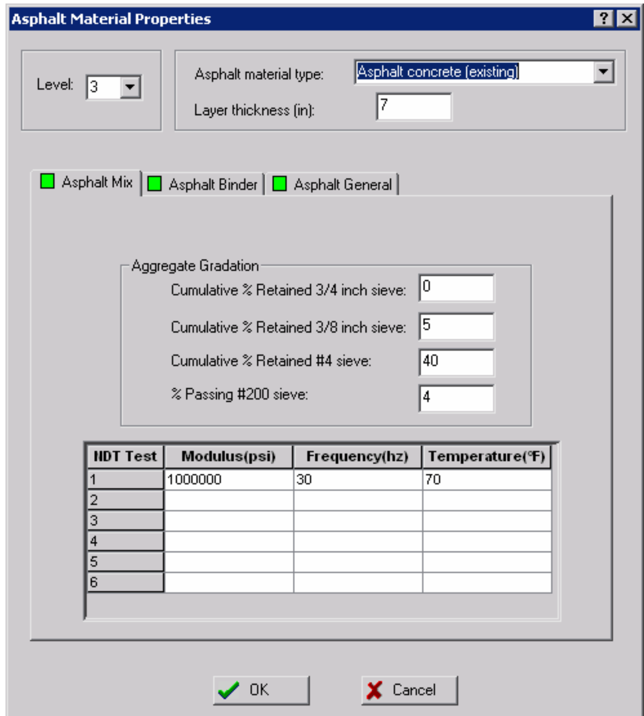


Figure D. 182. Existing AC layer material properties – *Asphalt Mix.*

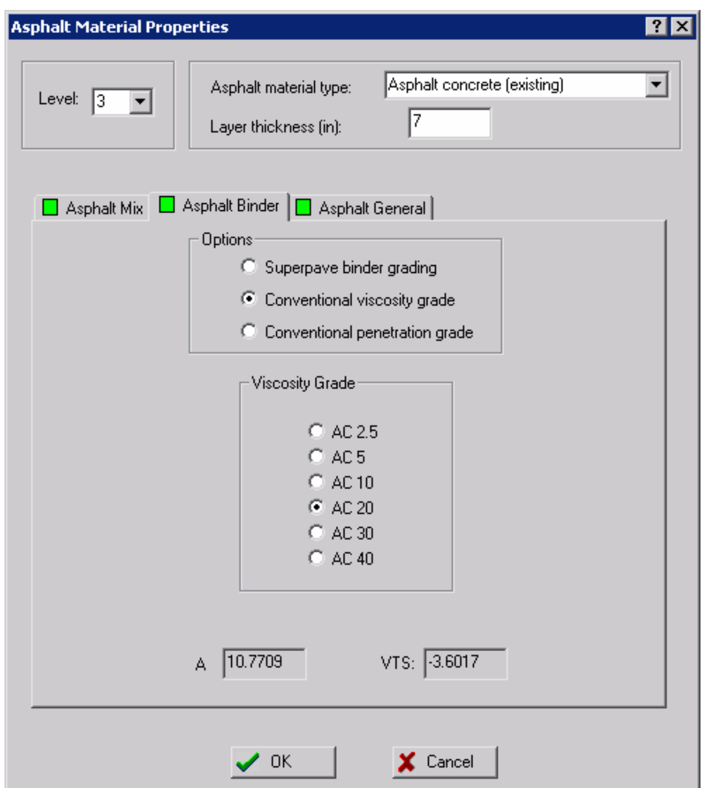


Figure D. 183. Existing AC layer material properties – *Binder Properties.*

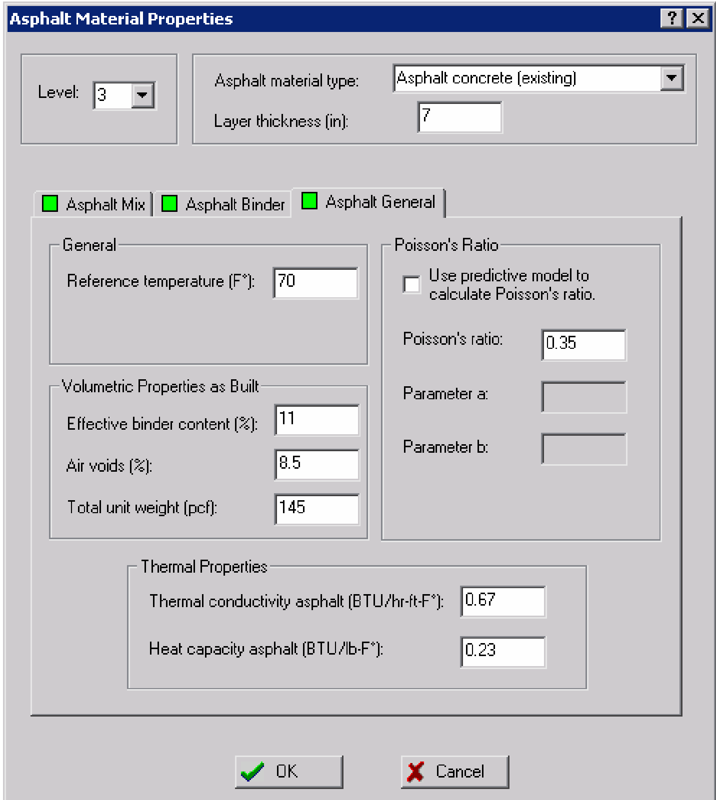


Figure D. 184. Existing AC layer material properties – *Asphalt General and Volumetrics.*

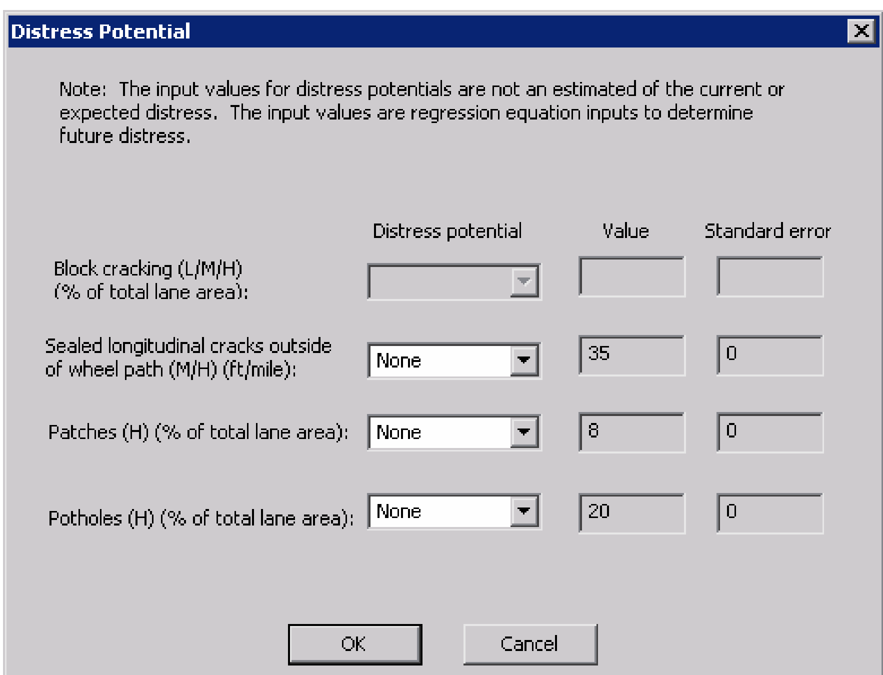


Figure D. 185. *Distress Potential* screen.

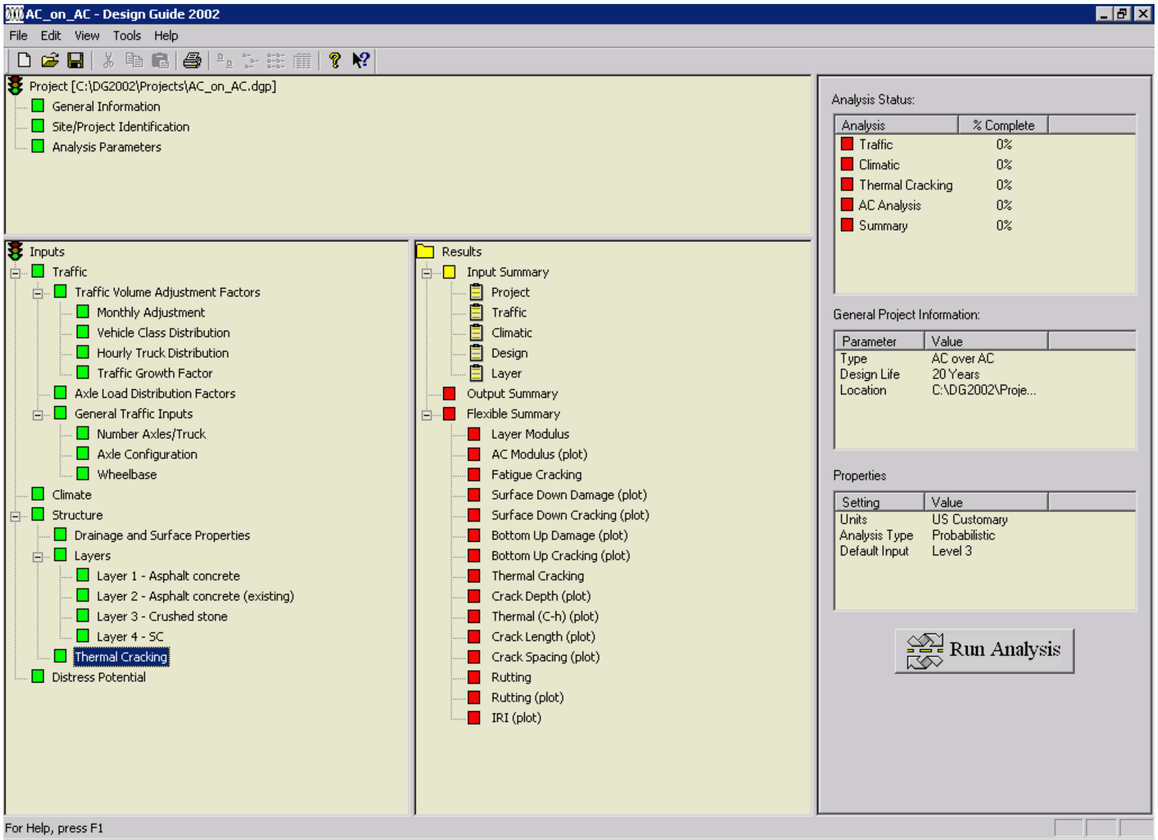


Figure D. 186. Program layout screen after completing all inputs.

D.6.2.9 Run Analysis

After all design inputs are provided, the Design Guide software has to begin the analysis process to predict the performance of the trial design over the design life of the pavement. Click on *Run Analysis*. The program runs the Traffic, Climate, Thermal Cracking, and AC Analysis modules and reports the analysis status on the upper right hand corner of the screen.

At the end of the analysis, the program creates a summary file and other output files in the project directory, *C:\DG2002\Projects\AC_on_AC*. The summary file is in Microsoft Excel format, named "*AC_on_AC.xls*," and is similar to the summary file created for new AC design. The summary file contains an input summary sheet, distress summary, and several performance charts, one for each distress type evaluated.

For the given trial design, the fatigue cracking, thermal cracking, rutting, and IRI predicted over the design life are shown in Figure D. 187, Figure D. 188, and Figure D. 189, respectively. The predicted IRI is shown in Figure D. 190. From these figures it is clear that the trial design satisfies the desired criteria at the selected level of reliability.

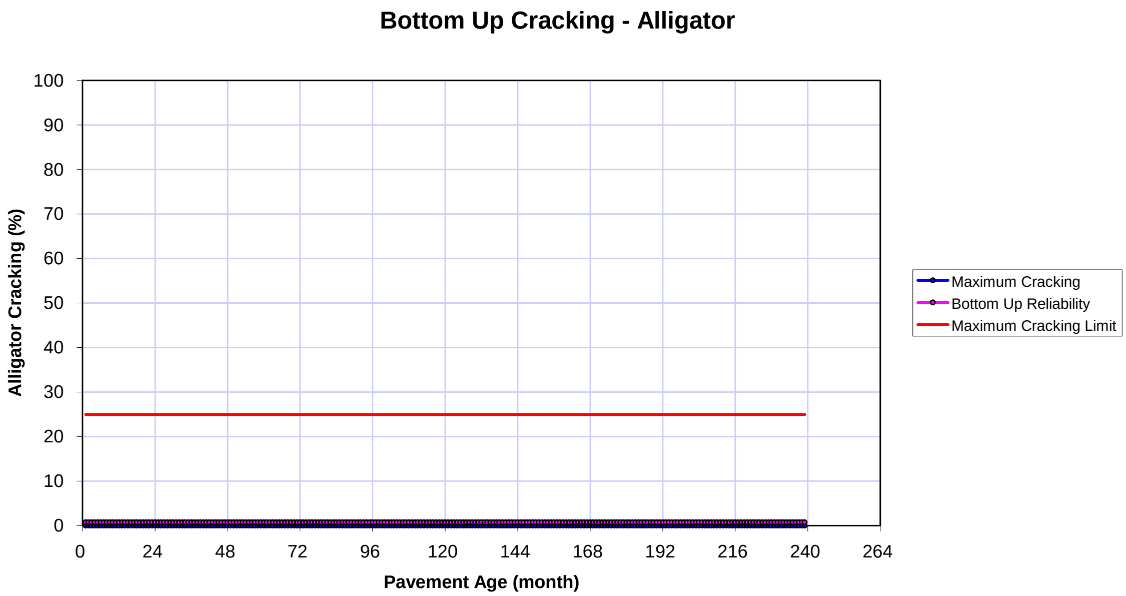


Figure D. 187. Fatigue cracking prediction over design life for the trial design.

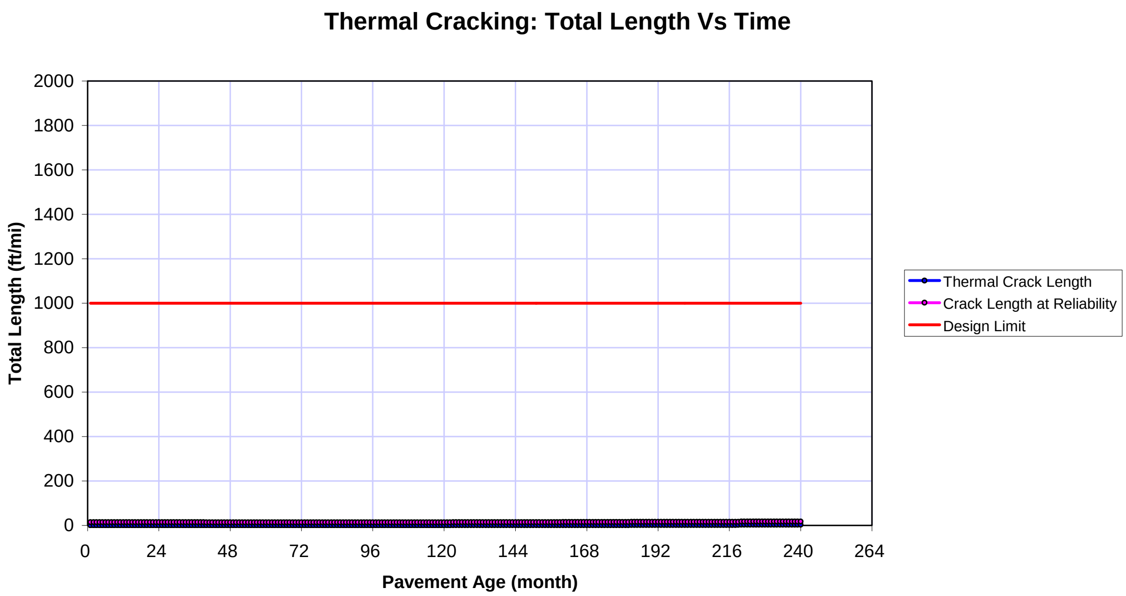


Figure D. 188. Thermal cracking prediction over design life for the trial design.

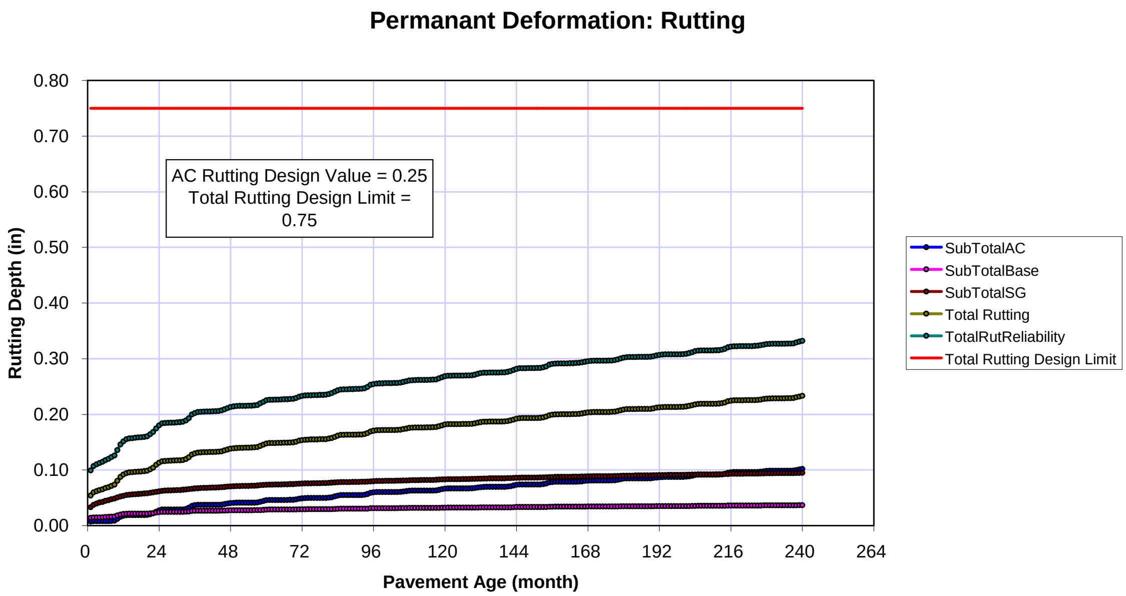


Figure D. 189. Rutting prediction for the trial design over the design life.

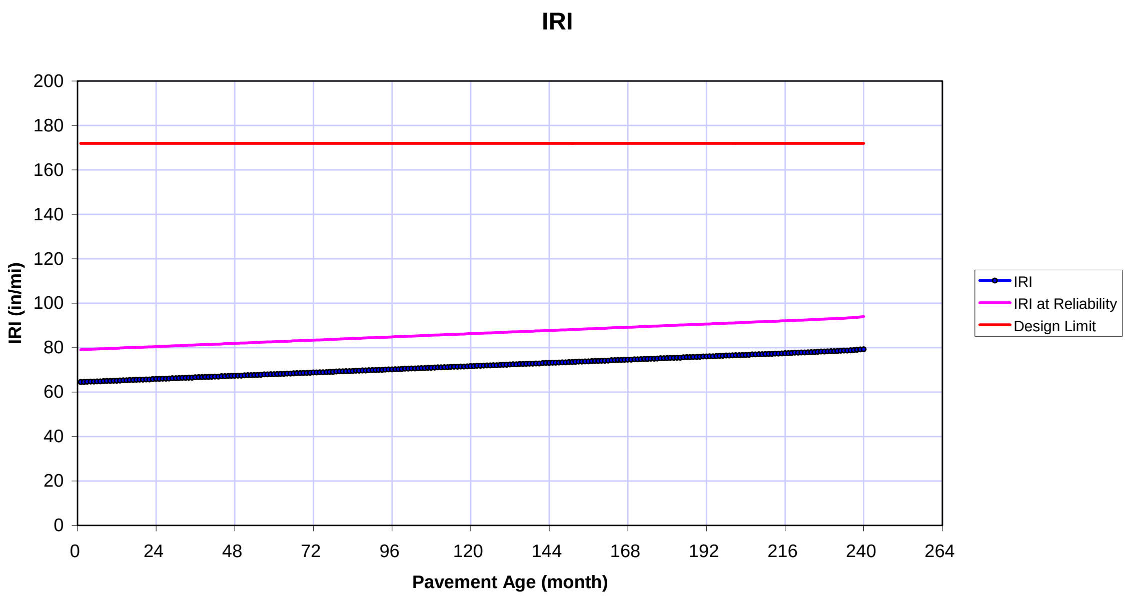


Figure D. 190. IRI prediction over design life for the trial design.

D.6.3 Modify Trial Design:

The trial design is a feasible design and need not be further modified. However, depending on the results of a trial design, the inputs should be modified to optimize the pavement structure chosen.

D.7 AC OVER EXISTING JPCP REHABILITATION DESIGN EXAMPLE

It is expected that, prior to performing AC rehabilitation design, the user is familiar with the use of the design software for the design of new AC sections (explained in detail in Section D.5).

The problem statement for this rehabilitation option of using an AC overlay to rehabilitate an existing JPCP is not covered in detail, to eliminate duplicated explanation of the various inputs and their use in the Design Guide software. Instead, all inputs required are tabulated in Tables D.7.1 and D.7.2.

Unlike the design examples for new flexible pavements, this example does not contain screen shots for all design inputs. It is expected that, with the experience of performing a new pavement design, the user will be able to make all inputs for the traffic, climate, and structural inputs for the existing pavements. However, those screen shots of the design software that are considered different from the previous examples, or those that are typical to this rehabilitation design type, are provided to guide the user with the design procedure. Users are urged to refer to Section D.5 where necessary.

D.7.1 Problem Statement for AC Rehabilitation

Table D.7.1 summarizes the general, traffic, climate inputs, and Table D.7.2 provides material properties, structure, and design features of the existing JPCP section. The information presented was obtained from a comprehensive evaluation of the jointed concrete pavement using procedures presented in PART 2, Chapter 5 of this Guide. The existing JPCP was constructed in September 1973 and is located in Columbus, Ohio. The ground water table is 10 feet deep at the project location. Using the data presented in Tables D.7.1 and D.7.2 as the basis, consider an AC overlay option.

D.7.2 Trial Design

This section is very brief compared to the corresponding sections of other design examples; references will be made to previous sections of this appendix, as appropriate, to guide the user through this example. The inputs parameters and their values are tabulated in Tables D.7.1 and D.7.2. Completing the design inputs will require the user to provide general, traffic, climate, materials, and rehabilitation inputs. Providing this general, traffic, and climate inputs involves the following steps:

1. Open a new project file in the Design Guide software as described in Section D.5.1.1.
2. Enter *General Information* inputs for this design type. In the overlay option, select *AC Over JPCP* from the drop-down menu.
3. Enter the design criteria on the *Analysis Parameters* screen as described in D.5.2.3.
4. Enter all *Traffic* inputs using the procedure described in Section D.5.3.

Table D.7.1. General, traffic, and climate inputs for AC overlay of existing JPCP.

Input Type	Variable	Value
General Inputs	Design Life	20 years
	Existing pavement construction	September, 1973
	Pavement overlay construction	September, 2003
	Traffic open	October, 2003
	Type of rehabilitation design	AC on JPCP
Analysis Parameters at **90** percent reliability	Initial IRI (in/mi)	63
	Terminal IRI (in/mi)	172
	Transverse cracking (% slabs cracked)	15
	AC surface-down cracking (Long. cracking) (ft/500)	1000
	AC bottom up cracking (Alligator cracking) (%)	25
	AC Thermal fracture (Transverse cracking) (ft/mi)	1000
	Chemically stabilized layer (Fatigue fracture)	25
	Permanent deformation (AC Only) (in)	0.25
	Permanent deformation (Total pavement) (in):	0.75
Traffic	Initial two-way AADTT	200
	Number of lanes in design direction	2
	Percent of trucks in design direction (%)	50
	Percent of trucks in design lane (%)	95
	Operational speed (mph)	60
	Traffic volume adjustment factors	Default level 3
	Truck Traffic Classification	Default TTC 1
	Hourly truck distribution	Default level 3
	Traffic Growth	4% compound
	Axle load distribution	Default level 3
	Traffic-General inputs: Number of axles/truck Axle configuration Wheelbase	Default level 3
Climate	Weather station	Columbus, OH
	Water table depth, feet	10

Table D.7.2. Structural and material properties of existing JPCP and AC overlay.

Input Type	Variable	Value
JPCP Design Features	Permanent curl/warp effective temperature difference (°F)	-10
	Joint Design	
	Joint spacing (ft.)	20
	Sealant type	Liquid
	Dowel diameter (in)	1
	Dowel bar spacing (in)	12
	Edge Support	None
	Long-term LTE(%)	N/A
	Widened Slab (ft)	N/A
	Base Properties	
	Base type	Granular
	Erodibility index	Fairly Erodible (4)
	Base/slab friction coefficient	0.85
	PCC-Base Interface	Unbonded
	Loss of bond age (months)	n/a
AC Overlay (Considered as Layer 1 in overlay analysis)	Material type	AC (existing)
	Layer thickness (in)	2
	Mix-Cumulative retained on ¾” sieve (%)	0
	Mix-Cumulative retained on $^{3}/_{8}$” sieve (%)	5
	Mix-Cumulative retained on #4 sieve (%)	40
	Mix-Passing #4 sieve (%)	4
	Binder viscosity grade, Conventional grade	AC-20
	Volumetrics-Mix binder content (%)	11
	Volumetrics-Air void (%)	8.5
	Total unit weight (pcf)	145
	Poisson’s ratio	0.35
	Thermal conductivity (BTU/hr-ft-F°)	0.67
	Heat capacity (BTU/lb-F°)	0.23
	Thermal cracking	Use defaults
Existing JPCP (Considered as Layer 2 in overlay analysis)	Layer thickness	10
	Unit weight, pcf	150
	Poisson’s ratio	0.20
	Thermal Properties	
	Coefficient of thermal expansion, in/in/°F x 10^{-6}	5.5
	Thermal conductivity (BTU/hr-ft-F°)	1.25
	Heat capacity (BTU/lb-F°)	0.28

Table D.7.2. Structural and material properties of existing JPCP and AC overlay, continued.

Input Type	Variable	Value
Existing JPCP, continued (Considered as Layer 2 in overlay analysis)	**Mix Properties**	
	Cement type	Type I
	Cement content (lb/yd^3)	600
	Water/cement ratio	0.42
	Aggregate type	Limestone
	PCC zero-stress temperature (F°)	Derived
	Ultimate shrinkage at 40% R.H (microstrain)	Derived
	Reversible shrinkage (% of ultimate shrinkage)	50
	Time to develop 50% of ultimate shrinkage (days)	35
	Current Method	Curing compound
	Strength Properties	
	Compressive strength from core, psi	6,000
Existing Granular Base, (Considered as Layer 3 in overlay analysis)	Material type	Crushed Stone
	Thickness, in	12
	Poisson's ratio	0.35
	Coefficient of lateral pressure, Ko	0.5
	Modulus, psi	35000
	Plasticity index, PI	1
	Passing No. 200 sieve, percent	6.2
	Passing No. 4 sieve, percent	54
	D60, mm	6
Subgrade (Considered in Layer 4 as in overlay analysis	Material type	SC
	Thickness, in	Semi-infinite
	Poisson's ratio	0.35
	Coefficient of lateral pressure, Ko	0.50
	Modulus, psi	24000
	Plasticity index, PI	15
	Passing No. 200 sieve, percent	25
	Passing No. 4 sieve, percent	90
	D60, mm	0.1
Rehabilitation	Percentage cracks in existing JPCP	20
	Percentage cracks repaired in restoration	20
Distress Potential	Sealed longitudinal cracks outside of wheel path	Medium
	Patches	Low
	Potholes (%):	High

5. Enter *Climate* inputs using the procedure described in Section D.5.4. Select the weather station for Columbus, Ohio, and use a water table depth of 10 feet. By this stage, the color-coded buttons adjacent to the different inputs should indicate that the user has provided all necessary inputs for the first three categories.

Next, the user will have to provide the inputs for the design structure, including properties of the existing pavement. Note that the *Structure* inputs are divided into four categories, *Design Features* of the Existing JPCP layer, *Drainage and Surface Properties*, *Layers*, and *Thermal Cracking*. The *Design Features* inputs were addressed in Section D.2.2.5.1. The other three categories are similar to the flexible design example in Section D.5.5.

For the design features of the existing pavement, enter the inputs given in Table D.7.2 as shown in Figure D. 191. Next, enter the *Drainage and Surface Properties* as described in Section D.5.5.1. Next, add layers to the pavement structure as described in D.5.5.2. Note that the program inserts the first two layers in the structure based on the type of design chosen. Insert the layers of the existing pavement as shown in Figure D. 192.

For the new AC layer, enter the material properties listed in Table D.7.2 as explained in Section D.5.5.2.1. Next, for the existing JPCP layer, enter the design inputs for the thermal, mix, and strength properties as shown in Figure D. 193, Figure D. 194, and Figure D. 195.

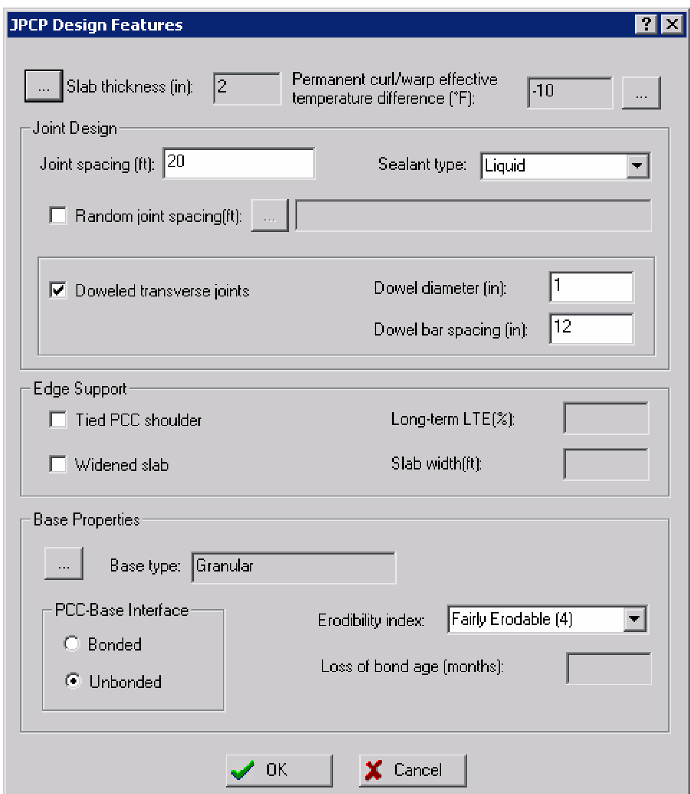


Figure D. 191. *Design Features* for the existing JPCP layer.

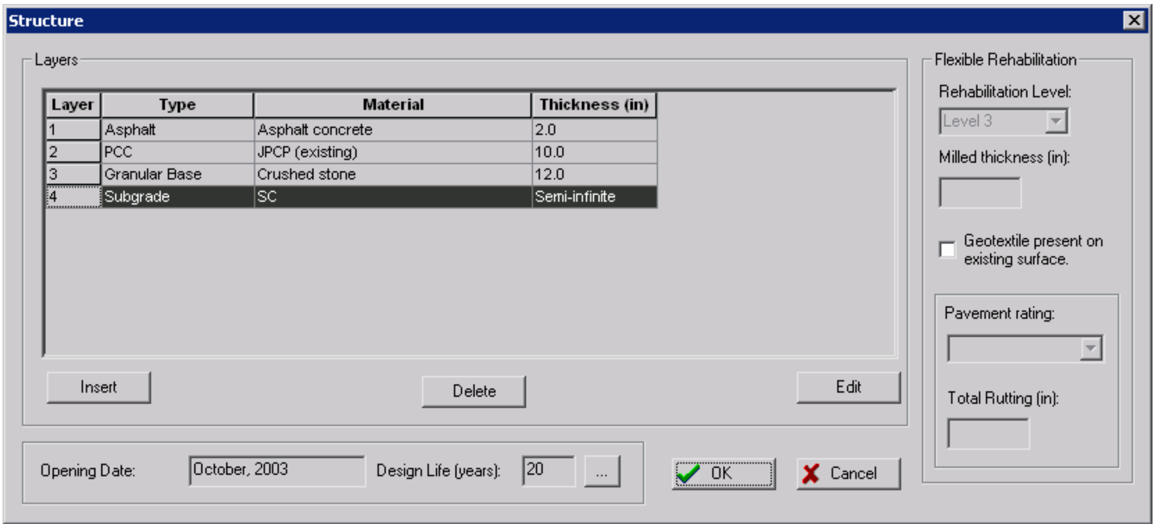


Figure D. 192. *Layers* screen for designing an AC overlay on existing JPCP.

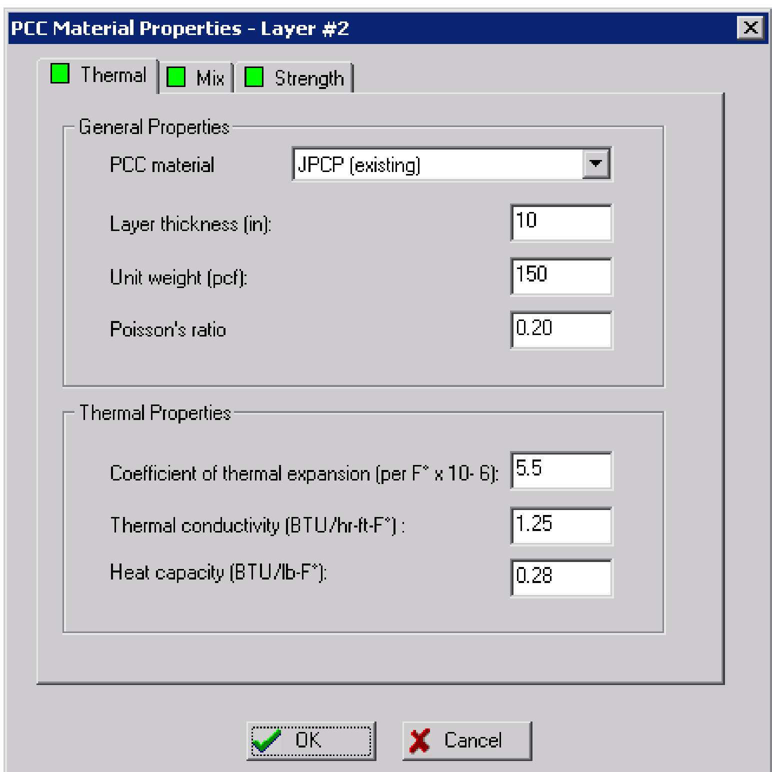


Figure D. 193. Existing JPCP layer Thermal properties screen.

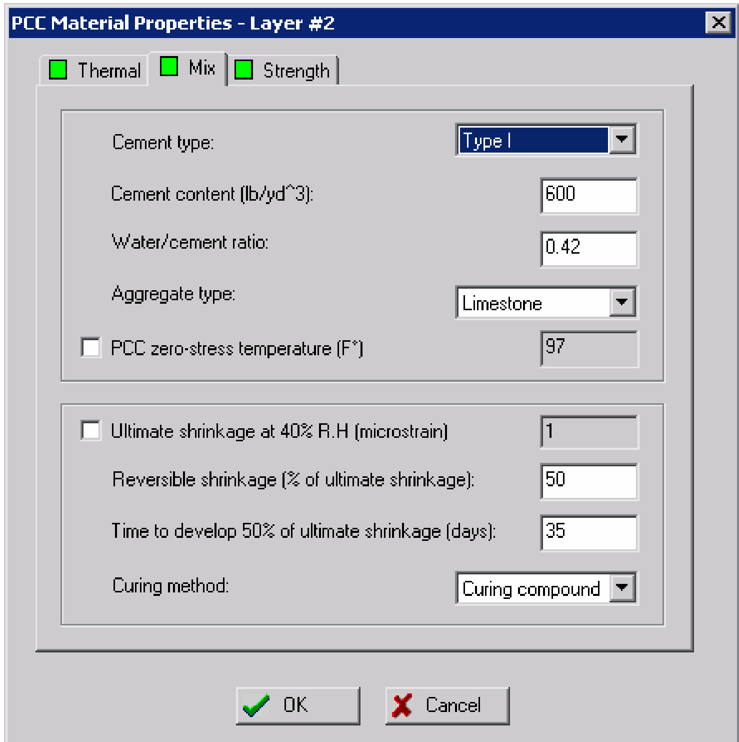


Figure D. 194. Existing JPCP layer *Mix* properties screen.

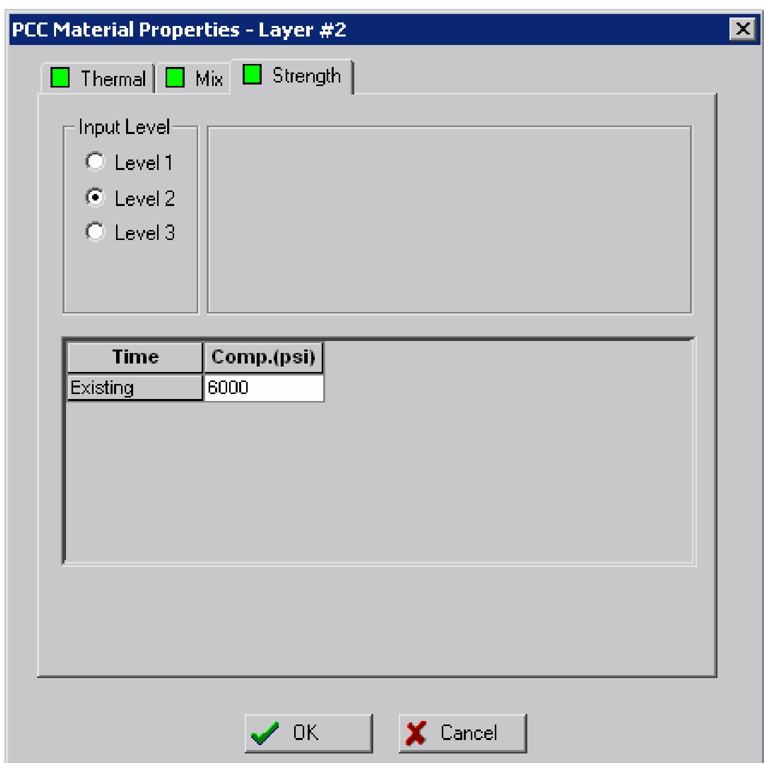


Figure D. 195. Existing JPCP layer *Strength* properties screen.

Note that, in Figure D. 194, the strength inputs are made at level 2 because the compressive strength from the cores has been provided. The value of 10,000 psi is the compressive strength of the concrete in the existing pavement in its current condition, and not its 28-day strength. Note that the software will not internally apply any other strength or modulus reductions to the JPCP layer.

Enter the material properties for the unbound layers using the input values listed in Table D.7.2 with the procedure described in D.5.5.2.2. Finally, accept the default thermal cracking inputs generated by the program on the *Thermal Cracking* screen.

Next, provide inputs to the *Rehabilitation* screen to indicate the damage in the existing pavement and the extent of repairs undertaken. These inputs are shown in Figure D. 196. The *Distress Potential* inputs provided in Table D.7.2 are to be entered as described in Section D.5.6.

This step completed the input process. Upon returning to the Program Layout screen, the color-coded icons should all turn green to indicate that the user has made all inputs necessary to run the analysis engine.

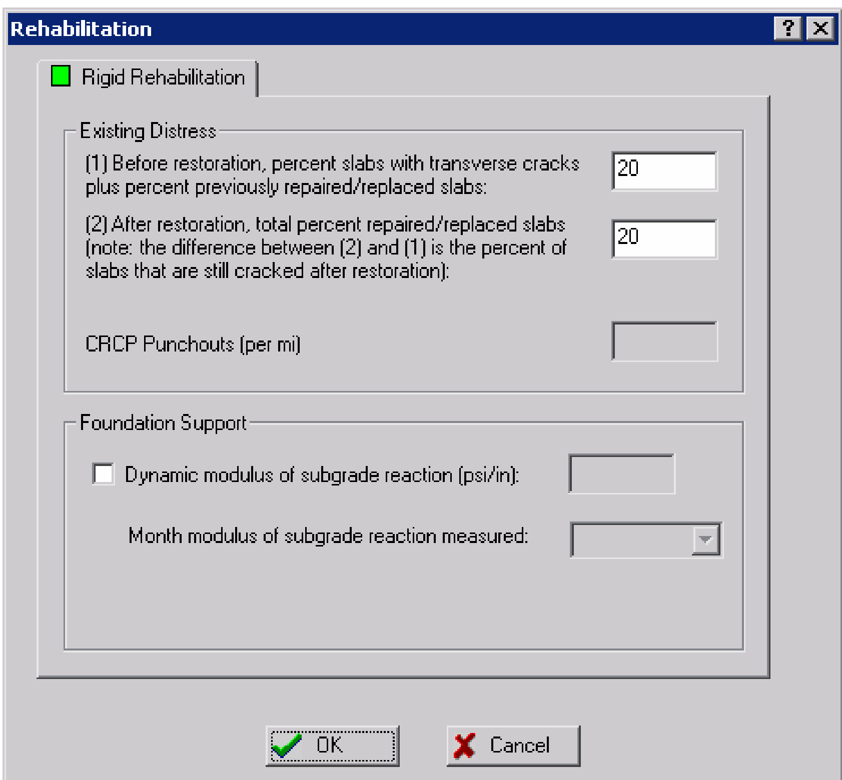


Figure D. 196. *Rehabilitation* screen for the AC overlay on existing JPCP.

D.7.3 Run Analysis

After all inputs are entered, click on the Run Analysis button. The Design Guide software first runs the traffic, climate, and material inputs. Next, the program analyzes the trial design to compute JPCP cracking and all other distresses associated with flexible pavements—fatigue cracking, thermal cracking, rutting, and roughness.

For the current example, the predicted performance for AC bottom-up cracking, thermal cracking, rutting, and smoothness are shown in Figure D. 197, Figure D. 198, Figure D. 199, and Figure D. 200. Since all the performance criteria are satisfied, the current trial design presents a feasible overlay option.

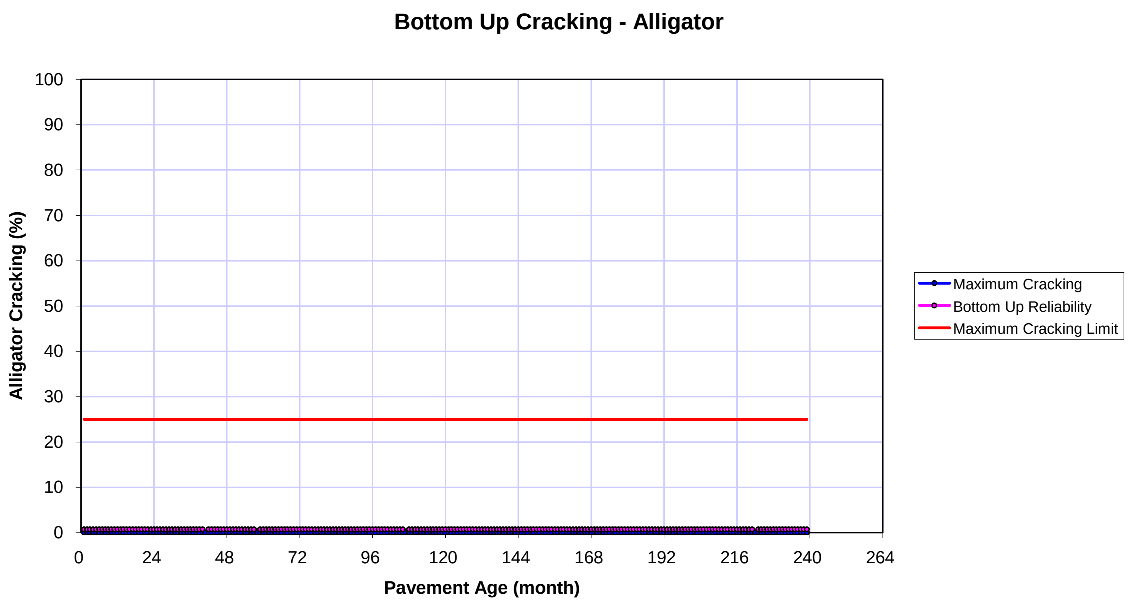


Figure D. 197. Fatigue cracking in AC overlay on existing JPCP.

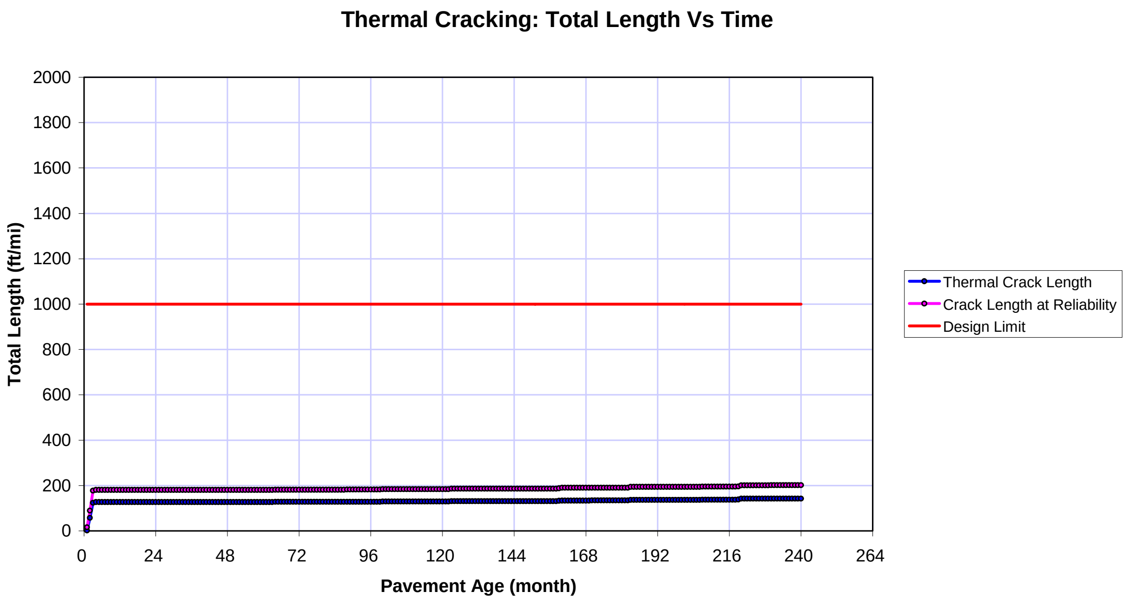


Figure D. 198. Thermal cracking in AC overlay on existing JPCP.

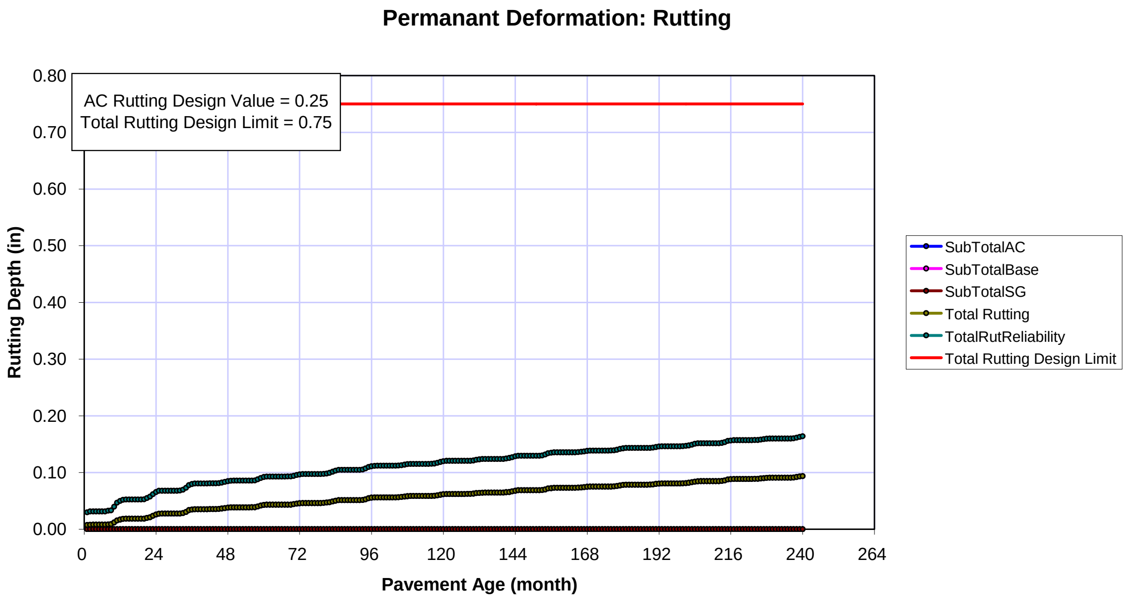


Figure D. 199. Rutting for AC overlay on existing JPCP.

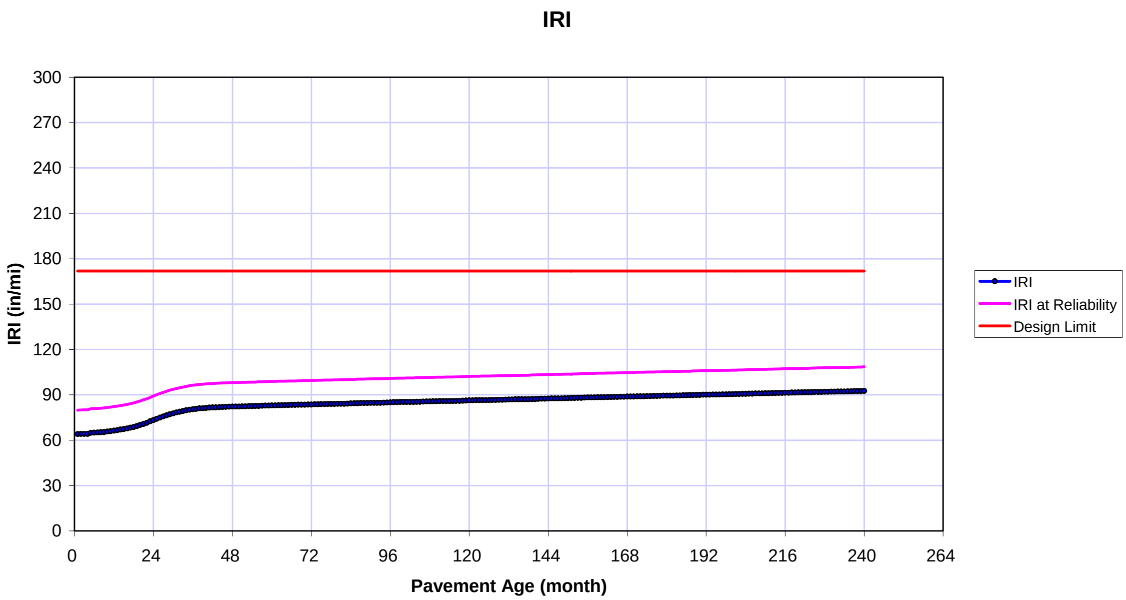


Figure D. 200. Predicted IRI over design life for AC overlay on existing JPCP.