Chapter 2

Literature review

2.1 Introduction

In this chapter the review will be focus on flexible pavement (surface course, base course and sub-base course), hot mix asphalt in flexible pavement (stone matrix asphalt mixes, open graded mixes and dense graded mixes), advantages of HMA, AASHTO Guide for design of pavement structures, Road Note 31, computer software, history of programing languages visual basic dot net and flexible pavement thickness design software.

2.2 Flexible pavement

Flexible pavement is surface constructed by bituminous (or asphalt) materials. These can be either in the form of pavement surface treatments such as a bituminous surface treatment (BST) generally found on lower volume roads and HMA, which were generally used on higher volume roads or high way network. Successful of HMA pavement requires good planning, design, construction (materials, subgrade, and workmanship) and planned future maintenance. Asphalt pavements are constructed of one or more course of HMA placed directly on the subgrade or on an aggregate base.

Flexible pavement are called “flexible” since the total pavement structure “bends” or “deflects” due to traffic loads. A flexible pavement structure is generally composed of several layers of material to accommodate this “flexing” effect.

The purpose of pavement is use for load support where flexible pavement uses more flexible surface course and distributes loads over a smaller contributing area. It relies on a combination of layers for transmitting load to the sub grade Flexible pavement generally require some sort of maintenance or rehabilitation every 10 to 15 years.

In order to take maximum advantage of this property, material layers are usually arranged in order of descending load bearing capacity with the highest load bearing capacity material (and most expensive) on the top and the lowest load bearing capacity material (and least expensive) on the bottom. This section describes he typical flexible pavement structure consisting of:

- *Surface course*. The layer in contact with traffic loads. It provides characteristic such as friction, smoothness, noise control, rut resistance and drainage (Figure 2.1). In addition, it prevents entrance of surface water into the underlying base, sub base and subgrade. This is the top layer and the layer that is exposed to traffic. It may be composed of one or several different HMA sub layers.

- *Base course.* The layer immediately beneath the surface (figure 2.1). It Provides additional load distribution and contributed to drainage and frost resistance. This is the layer directly below the HMA layer and generally consists of aggregate (either stabilized or UN stabilized).
- *Sub base course.* This is the layer (or layers) under the base layer (figure 2.1). The layer between the base course and subgrade. The sub base generally consists of lower quality materials than the base course but better than the subgrade soils. A sub base course is not always needed or used.

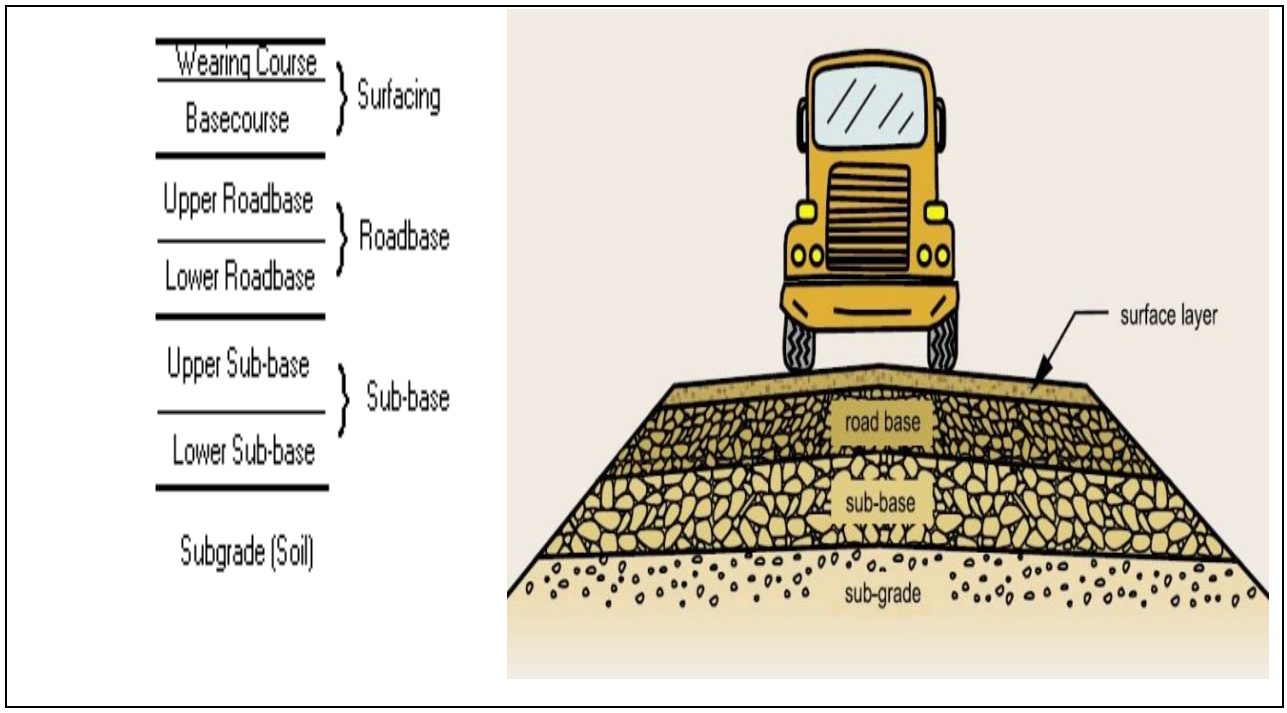


Figure 2.1: Pavement Structure Layers for Flexible Pavement

2.2.1 Surface Course

Obviously, surface course is the layer in contact with traffic loads and normally contains the highest quality materials. Surface course play an important role in characteristic of friction, smoothness, noise control, rut and shoving resistance and drainage. Furthermore, surface course serves to prevent the entrance of excessive quantities of surface water into the underlying base, sub base and subgrade. This top structural layer of material is sometimes subdivided into two layers:

1) *Wearing course*. This is the toper layer in pavement structure and direct contact with traffic loads. A properly designed (and funded) preservation program should be able to identify pavement surface distress while it is still confined to the wearing course.

2) *Binder course*. The purpose of this layer is to distribute load from wearing course. This layer provides the bulk of the HMA structure.

2.2.2 Base course

The base course is a course of specified material and design thickness, which support the structural course and distributes the traffic loads to the sub base or subgrade. The base course is immediately beneath the surface course. It provides additional load distribution and contributes to drainage and frost resistance. Different base course material may have different thickness. Base courses are usually constructed out of:

1) *Aggregate,* are the most typically constructed from durable aggregates that will not be damage by moisture or frost action. Aggregates can be either stabilized or unsterilized.

2) *HMA*, used where high base stiffness is desired. In surface course HMA mixes, it usually contains larger maximum aggregate size (open graded) and subjected to more lenient specifications.

2.2.3 Sub-base course

The sub base course is between the base course and the subgrade. The sub base consists of lower quality materials than the base course but better that subgrade soils. The sub-base consists of granular material – gravel, crushed stone, reclaimed material or a combination of these materials. The sub base is a layer of specified material and design thickness that support the base. This generally is limited to use with a composite base:

For a pavement constructed over a high quality, stiff subgrade may not need the additional features offered by sub base course. However, a pavement constructed over a low quality soil such as swelling clay may require the additional load distribution characteristic that require sub base course to replace and support the poor quality subgrade. It functions primarily as structural support but it cans also:

1) Minimize the intrusion of fines from the subgrade into the pavement structure.
2) Minimize frost action damage.
3) Provide a working platform for construction.

2.3 Hot Mix Asphalt in flexible pavement

Obviously, there are three of the most common types of HMA mix types used in flexible pavements (Figure 2.2) known as Dense-Graded Mixes (HMA), Stone Matrix Asphalt (SMA) Mixes and Open –Graded Mixes (HMA).

2.3.1 Stone Matrix Asphalt (SMA) Mixes

Stone matrix asphalt (SMA) relatively has been use as a surface course to support heavy traffic loads and resist studded tire wear. SMA is a gap-graded HMA develop to maximize rutting resistance and durability. Since aggregates do not deform as much as asphalt binder under load, this stone –on – stone contact greatly reduce rutting. SMA benefits include we weather friction due to a coarser surface texture, lower tire noise due to a coarser surface texture and less severe reflective cracking.

SMA is generally more expensive that a typical dense-graded HMA because it requires more durable aggregates, higher asphalt content, modified asphalt binder and fibers. The materials to construct SMA usually are:

1) Gap-graded aggregate (coarse aggregate, manufactured sands and mineral filler all combined into a final gradation).
2) Asphalt binder (typically with a modifier).

2.3.2 Open – Graded Mixes (HMA)

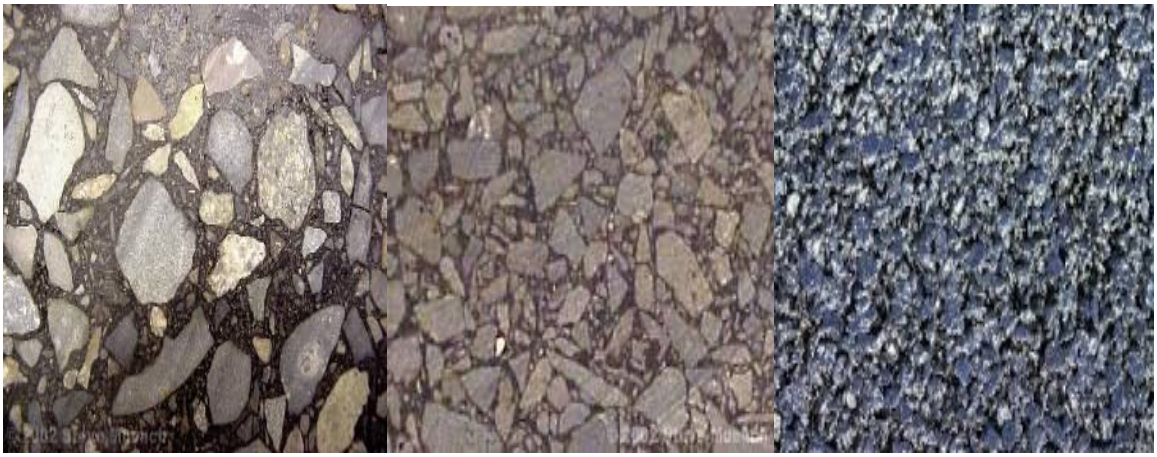
Previously, dense-graded and SMA mixes usually are not permeable. Therefore, an open-graded HMA mixture is designed to be water permeable. Open-graded mixes use only crushed stone or gravel and a small percentage of manufactured sands. There are three types of open- graded mixes typically used nowadays:

1) *Asphalt treated permeable bases (ATPB),* Used as a drainage layer below dense-graded HMA and SMA.
2) *Open-graded friction course (OGFC).* Typically, 15 percent air voids, no minimum air voids specified, lower aggregate standards then PEM.
3) *Porous European mixes (PEM).* Typically, 18-22 percent air voids, specified minimum air voids, higher aggregate standards than OGFC and requires the use of asphalt binder modifiers.

The function of OGFC and PEM are used as surface only. They reduce tire splash/spray in wet weather and typically, result in smoother surfaces than dense graded HMA. Their high air voids trap road noise and thus reduce tire road noise by up to 50 percent (10dBA).

2.3.3 Dense – Graded Mixes

A dense-graded mixes is a well-graded HMA mixture intended for general use. When properly designed and constructed, a dense-graded mix is relatively impermeable. Dense-graded mixes are generally referred to by their nominal maximum aggregate size. The purpose of Dense-graded mixes is suitable for all pavement layers and for all traffic conditions. They work well for structural, friction, leveling and patching needs. Figure 2.3 show the different between Dense-Graded HMA and SMA with a bit shinier from the extra asphalt binder.



Dense-Graded HMA SMA Surface OGFC Surface

Figure 2.2: Different Types of Hot Mix Asphalt (HMA) in Flexible Pavement

Figure 2.3: Dense Graded HMA (Left) VS SMA (Right)

2.4 Advantages of HMA

There is several advantage of HMA shown as below:

1) Versatility:

- HMA pavements can be designed to handle any traffic loading, soils and materials, and can be used to salvage old pavements as well as to build new ones.
- Phased construction can easily be incorporated.

2. Economy:

- HMA pavements are economical to construct, can be constructed rapidly, immediately ready for use, can be recycled, require minimal maintenance and provide outstanding performance.
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3. HMA pavements are not affected by ice control chemicals.

4. Building and site esthetics are enhanced.

5. Traffic noise is minimized when HMA pavement is used.

6. Pavement striping is highly visible on the black HMA surface.

2.5 AASHTO Guide for Design of Pavement Structures

In 1972, the AASHTO pavement design guide was first published as an interim guide. Update to the guide was subsequently published in 1986 and 1993; a new mechanistic-based design guide is currently planned for completion in 2002.

The AASHTO design procedure is based on the results of the AASHTO Road Test that was conducted in 1958-1960 in Ottawa, Illinois (figure 2.4). Approximately 1.2 million axle load repetitions were applied to specially designed test tracks in the largest road test ever conducted

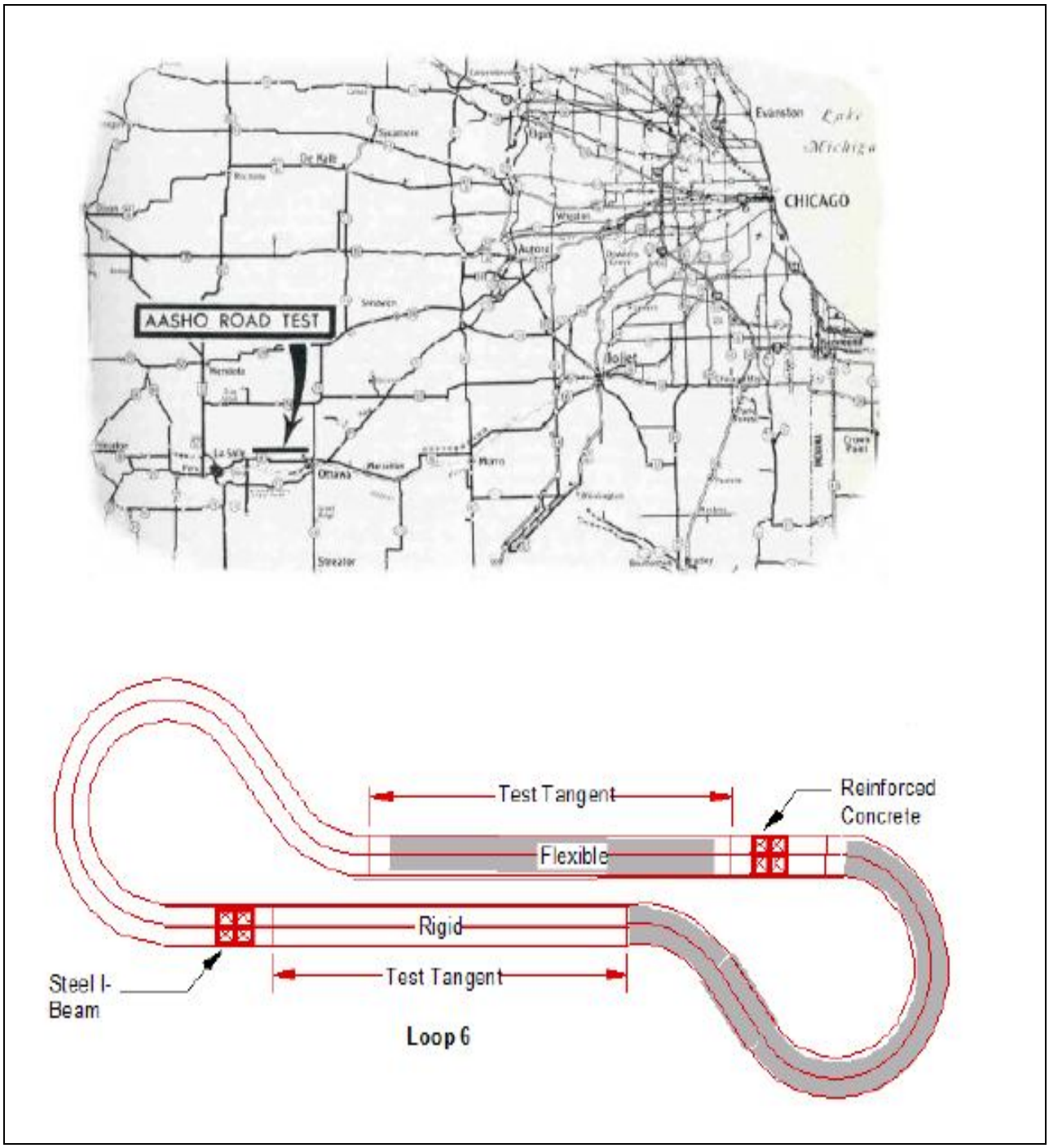

Figure 2.4: AASHTO Road Test

2.5.1 Pavement Thickness Design

The American Association of State Highway Officials (AASHO) has carries out a Road Test at Ottawa; Illinois provided the basis for calculating the required pavement thickness. Models (Road Test) were developed to related pavement performance, vehicle loading, strength of roadbed soils, and the pavement structure.

Equation 2.1 the AASHTO Empirical Equation used by the Department for design purpose. Empirical equations are used to relate observed or measurable phenomena of pavement characteristics.

$$\log_{10} W18 =$$

$$ZR \times S0 + 9.36 \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40+\frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10} MR - 8.07 \qquad \textbf{(2.1)}$$

Where:

W18 = Predicted number of 80 KN (18.000 lb) ESALs

ZR = Standard normal deviate

S0 = Combined standard error of the traffic predication and performance prediction

SN = Structural Number (an index that is indicative of the total pavement thickness required)

= a1 D1 + a2 D2 m3 + a3 D3 m3 + …

ai = ith layer coefficient

Di = ith layer thickness (inches)

mi = ith layer drainage coefficient

ΔPSI = difference between the initial design serviceability index, Po, and the design terminal serviceability index, pt

MR= Subgrade resilient modulus (in psi)

The purpose of the AASHTO model is to calculate the Required Structural Number (SNR) in the pavement thickness design process (AASHTO, 1993). SNR is the strength of the pavement the must be constructed to carry the mixed vehicle loads over the roadbed soil, while providing satisfactory during the design period. Therefore, by conducting the SNR, the pavement layer thickness can be calculated.

Accumulated 18-kip Equivalent Single Axle Loads ESAL or (ESALD)

The predicted loading is simply the predicted number of 80 KN (18.000 lb) ESALs for the pavement experience over its design lifetime. The accumulated 18-kip Equivalent Single Axle Loads (ESAL) is the traffic load information used for pavement thickness design. The accumulation of the damage caused by mixed truck traffic during a design period is referred to the accumulated 18-kip Equivalent Single Axle Loads ESAL or (ESALD).

Reliability

The reliability of the pavement design process is the probability that a pavement section design using the process will perform satisfactory over the traffic and environmental conditions for the design period. The use of Reliability (%R) also to tailor the design to more closely match the needs of the project. It is the probability of achieving the design life that the Department desires for that facility. The ZR and S0 variables account for reliability.

Resilient Modulus (MR)

Subgrade support is characterized by the subgrade's resilient modulus (MR). The Resilient Modulus (MR) is a measurement of the stiffness of the roadbed soil.

Standard Normal Deviate (ZR) is the corresponding Reliability (%R) value that has been converted into logarithmic form for calculations purposes.

Standard Deviation (S0) The AASHTO design guide recommends an approximate range of 0.4 to 0.5 for flexile pavements, 0.45 is used in the design to account for variability in traffic load prediction and construction.

Present Serviceability Index (PSI) is the ability of a roadway to serve the traffic, which uses the facility. A rating of 0 to 5 is used with 5 being the best and 0 being the worst. The PSI decreases as the road condition decreases due to deterioration.

Change in Serviceability (ΔPSI) is the difference between the Initial Serviceability (PI) and Terminal Serviceability (PT).

Initial Serviceability (PI) is the condition of a newly constructed roadway.

Terminal Serviceability (PT) is the condition of a road that reaches a point where some type of rehabilitation or reconstruction is warranted.

2.5.2 AASHTO Road Test Limitation and Assumption

It is extremely important to know the equation's limitations ad basic assumptions when using the 1993 AASHTO Guide empirical equation, Otherwise, This can lead to invalid results at the least and incorrect results at the worst.

The empirical equations develop from AASHTO Road Test were related to loss in serviceability, traffic, and pavement thickness. Through the specific conditions of the AASHTO Road Test, these equations have some significant limitations:

- The equations were developed based on the specific pavement materials and roadbed soil present at the AASHTO Road Test.

- The equations are based on an accelerated two-year testing period rather than a longer, more typical 20+year pavement life. Therefore, environmental factors were difficult if not impossible to extrapolate out to a longer period. Thus, the equations were developed based on the environment at the AASHTO Road Test only.
- The equations were developed based on the loads of operating vehicles with identical axle loads and configurations, as opposed to mixed traffic.

Therefore, In order to apply the equations developed as a result of the AASHTO Road Test, some basic assumptions were made.

- Loading can be applied to mixed traffic by use of ESALs.
- The accelerated testing done at the AASHTO Road Test (2-year period) can be extended to a longer design period.
- The characterizations of material may be applied to other surfaces, bases, and sub bases by assigning appropriate layer coefficients.
- The characterization of subgrade support may be extended to other subgrade soil by an abstract soil support scale.

2.6 Road Note 31

Road Note 31 which also known as overseas road notes was developed by Transport Research Laboratory (TRL) to design flexible pavement thickness besides understanding the behaviors of road building material, also interaction in pavement structural layers design. In advance, Road Note 31 is confident to be applying in tropical and sub tropical regions associated with climate and various types of material and reliable road maintenance levels (Road Note 31 Guide).

Road note 31 is the experience base design according to the previous successful project had been done by professional body or senior engineer, thus, a Road Note 31 structural catalogue (figure 2.5) had been production in order to design the flexible pavement thickness design base on the traffic and subgrade strength classes' requirement.

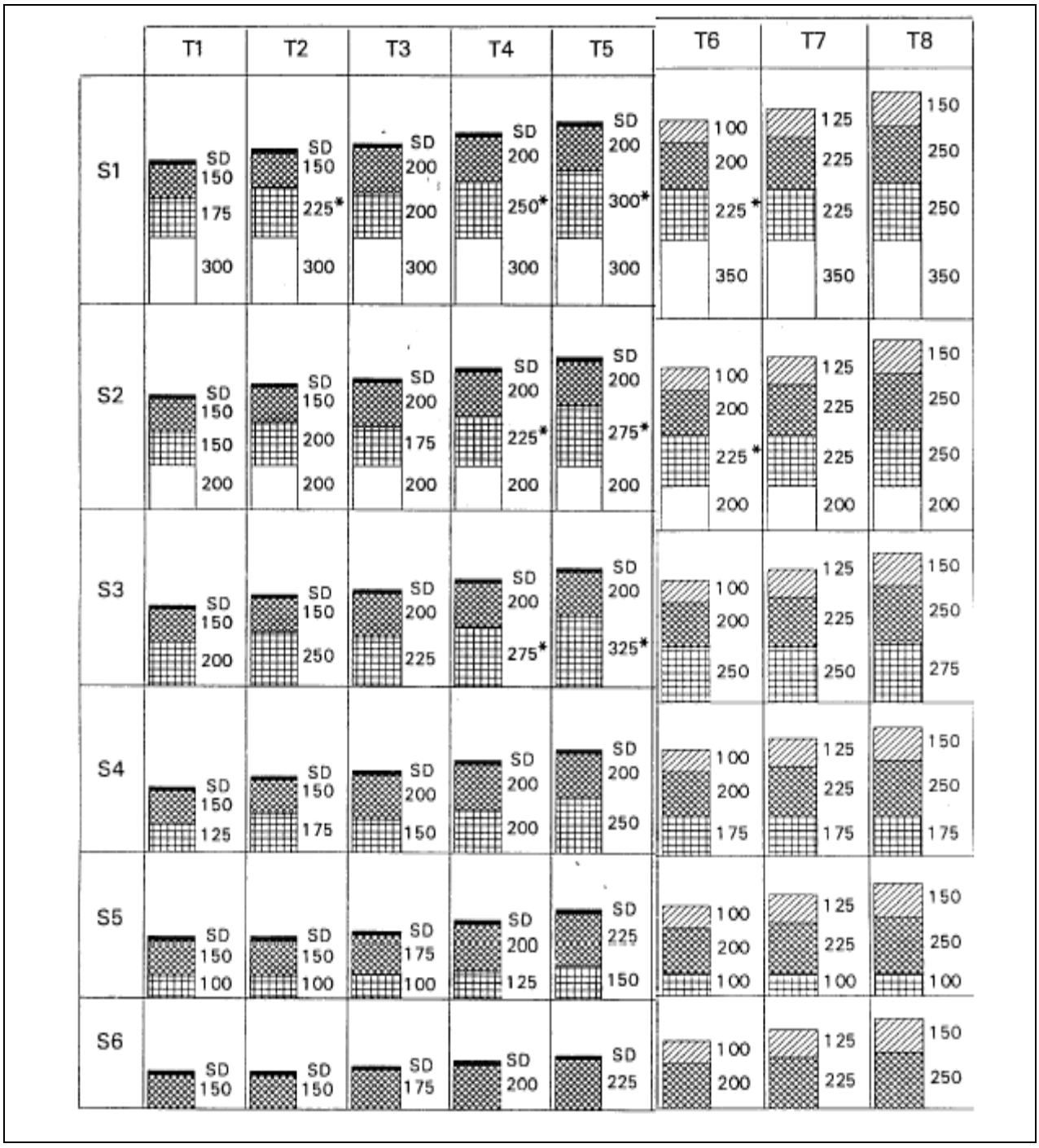

Figure 2.5: Road Note 31, Structural Catalogue

2.7 Computer Software

Computer software is a general term used to describe a collection of computer program, procedures and documentation that perform some tasks on a computer system. Software encompasses an extremely wide array of products and technologies developed using different techniques such as programming languages.

In computer software development, there are four steps show as below need to be consider known as design, code, test and maintain. By following these four steps of program, development will enhance the reputation of programmer and develop a successful computer software program.

Design

The first step in developing a computer program is design. Producing a good, design leads to efficient code, which does what it is meant to in the best way possible.

Design processes include defining the data requirements, objective, scope and chosen of function or process to be uses clear output to be achieved.

Coding

The second step is known as coding. The program is written in the language chosen and ensures the language syntax rules followed precisely, techniques such as debugging, dry running programs and meticulously checking syntax can help to find errors.

Testing Computer Programs

The purpose of testing is to ensure that the program works as expected. There are many different ways of testing includes choosing the appropriate tests for the particular program.

Maintenance of Computer Software

Maintaining of computer software is importance to the changes of requirements for programs from time to time. Simple steps such as commenting code can help, as well as providing a statement of intent at the top of the code and a history of changes.

To become a successful programmer in developing computer program, the following steps should be considering.

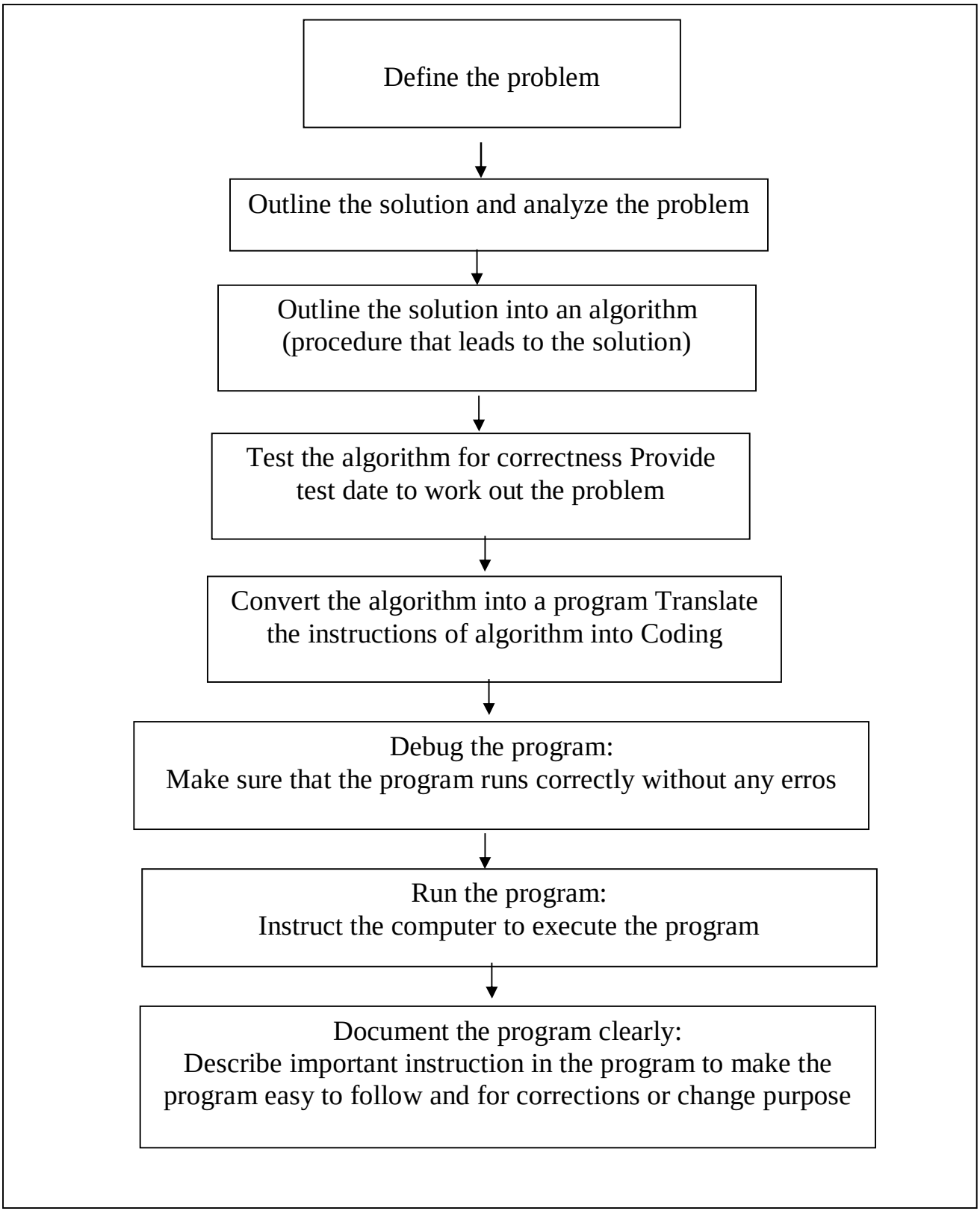

Chart 2.1: Software Development Process

Refer to Gabriel's paper; his arguments can be generalized as a single point: "make it simple in four aspects of his theory. The language should easy to be accepted and available on a wide variety of hardware, easy to learn and should be similar to existing language.

1) Carefully choose the problems to through innovation and maintain the computing speed achieved by hardware development.
2) Provide a simple model to access it performance. This will help programmer write more efficient program.
3) Successful language should have mathematical simplicity.

2.7.1 History of programming languages

The history of programming language were start developed since 1950s and until the 1990s (figure 2.6). Many "rapid application development" languages emerged, which usually came with an IDE, garbage collection, and were descendants of older languages. All such languages were object-oriented. These included object Pascal, Visual Basic and C#.

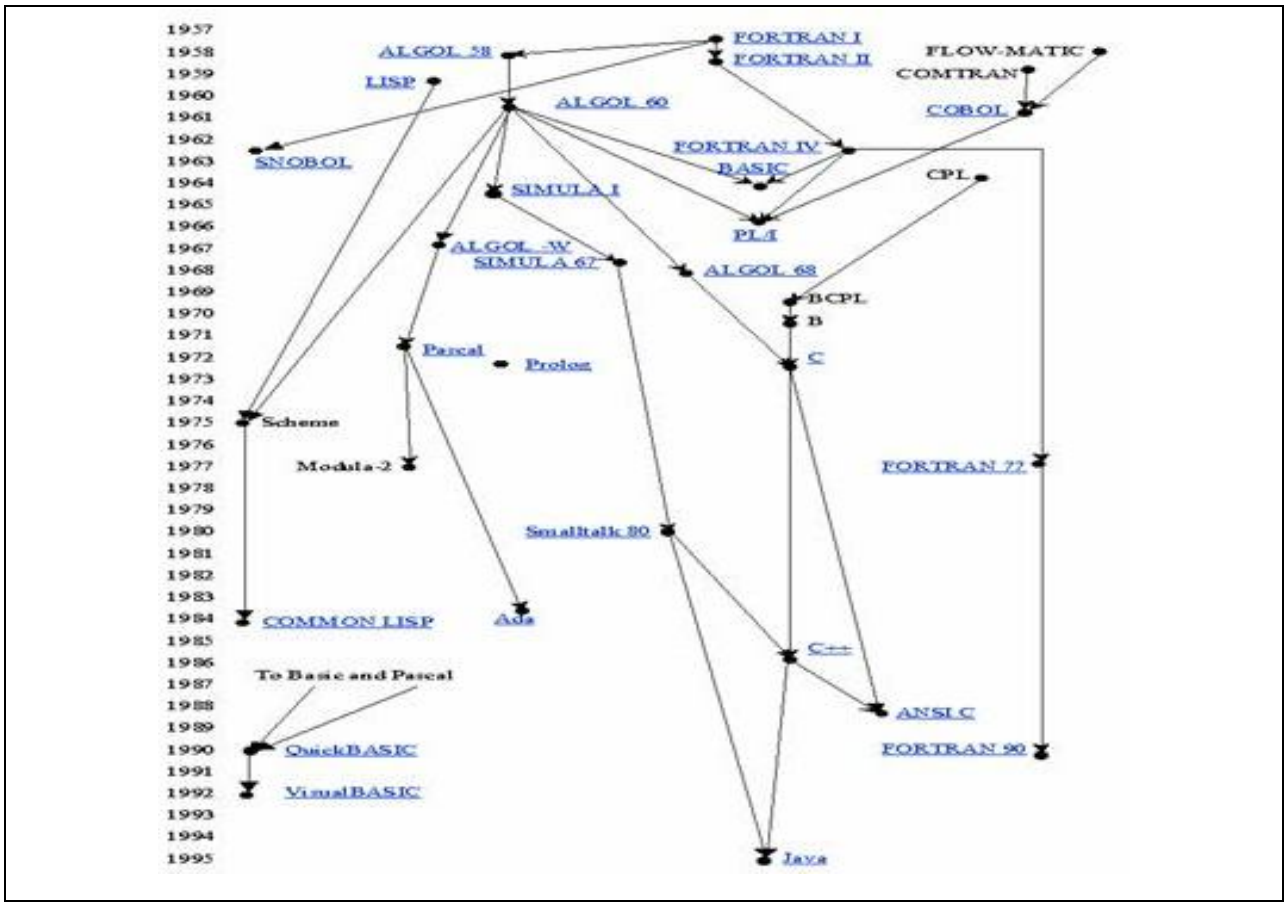

Figure 2.6: History of Programing Language

2.7.2 Visual Basic

2.7.2 .1 Overview of Visual Basic

Visual Basic is just one of dozens of programming languages, but it's one of the best and most successful. It is one of the most popular languages in the world. It is popular with business and in education. It's object-oriented and can do almost anything. Visual Basic is simple, the commands are straightforward, and the basics are easy to grasp. With it, the beginner programmer can write and run programs from the first day.

It is powerful – powerful enough to take on almost any development project. Programs written in earlier versions of Visual Basic will usually convert and run in the latest version.

Visual Basic comes in several flavors, from the free Express Edition available as a download from Microsoft to the Professional version that is a part of Visual Studio. It must be installed on the computer and the programmer must know how to start it, navigate through the folders on the system, open and save files, and, in general, use a computer.

2.7.2 .2 VB Project Basic Tasks

Most computer programs complete the same basic set of tasks, and this dissertation project, complete them in the same order. Every program has input, processing, and output. Input puts data into the computer. It might be a number or some text. It might be data from a file. Depending on the system and the task, it could be input from a pen, mouse, or keyboard. Processing is the task: In a business program it could be the payroll calculations; in a game, it may move the pieces on a board; in an air conditioning system, it may turn on the fan or turn off the heat, and in this project it can be calculation of layers thickness and the total cost of the pavement project materials and construction. Processing is the work of a program. Output is the results, the answers. Often the results are displayed on the screen, but it could also be a printout or a file. Every program works with data. The data could be the

numbers or text used by the program. In this project, the data could be the reliability, the standard deviation road sections samples, equivalent axial load factor, design period, elastic modulus for pavement layers, etc.

These data must be declared before it can use them. Declarations tell the computer what type of data it has for the program. Declarations usually come at the beginning of a task.

In terms of pavement design, the declarations are the standard deviation, reliability, design period, and elastic modulus, are an examples of inputs, the processing is to calculate different types of data such as, severability index, annual growth of traffic, resilient modulus.

The output of the program is to determine the pavement design depend on the layer thickness and the cost.

2.7.2 .3 Code Files/Program

Visual Basic .NET projects have a folder containing several files and other folders that contain files. These files are needed to create the final program. All of them are used in development. The final program is an executable file with an .exe extension. It can run this standalone program even if there is not Visual Studio. To create or modify a program, there is need for project folder and its files. These are used to create the executable file.

2.7.3 Important Components in Visual Basic

Visual Basic is divided into 5 important components as shown in Figure 2.7

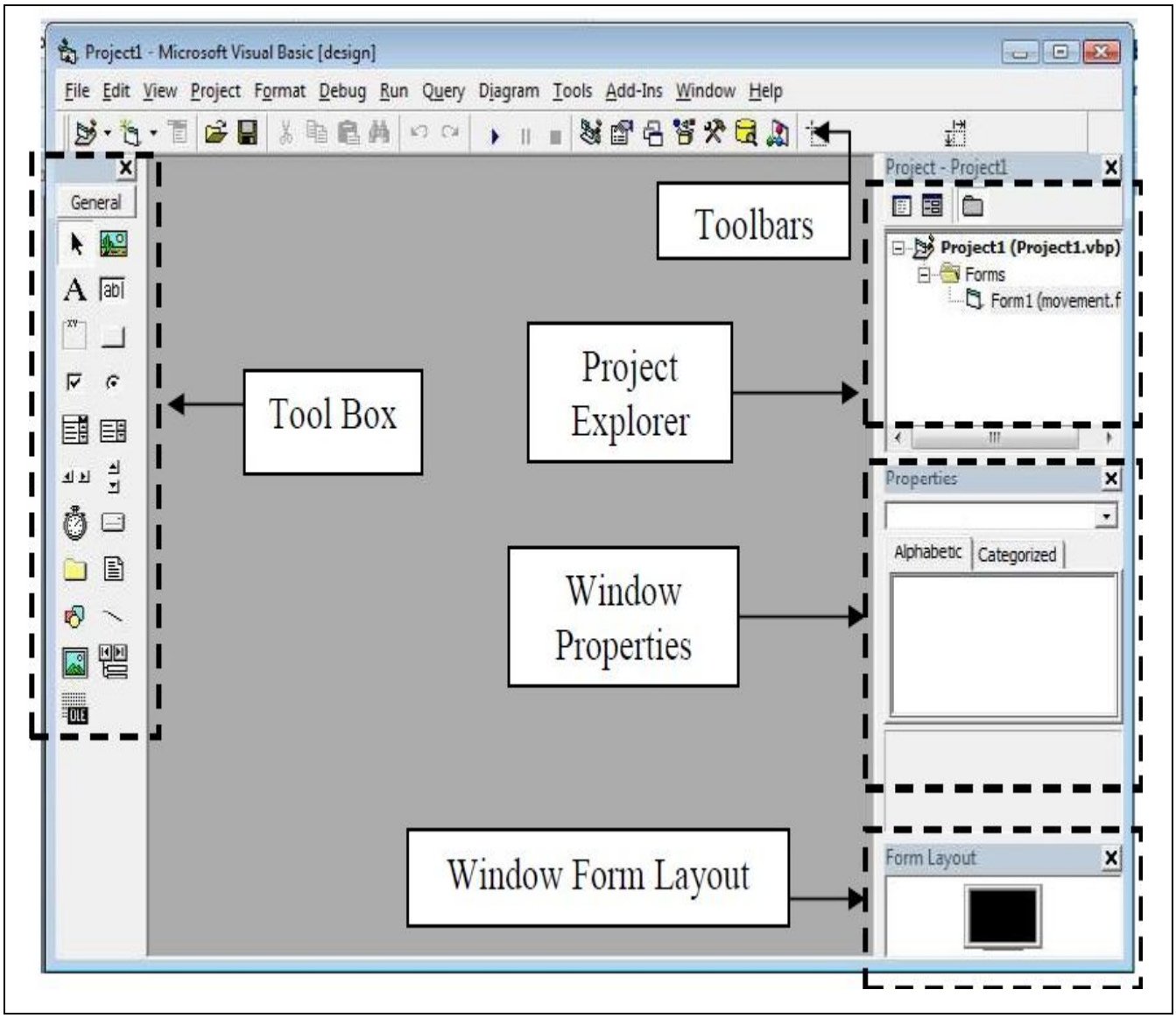

Figure 2.7: Important Component in Visual Basic

Project explorer (figure 2.8) is a option function in visual Basic where it's include 3 main components known as view coding, view form and view folder.

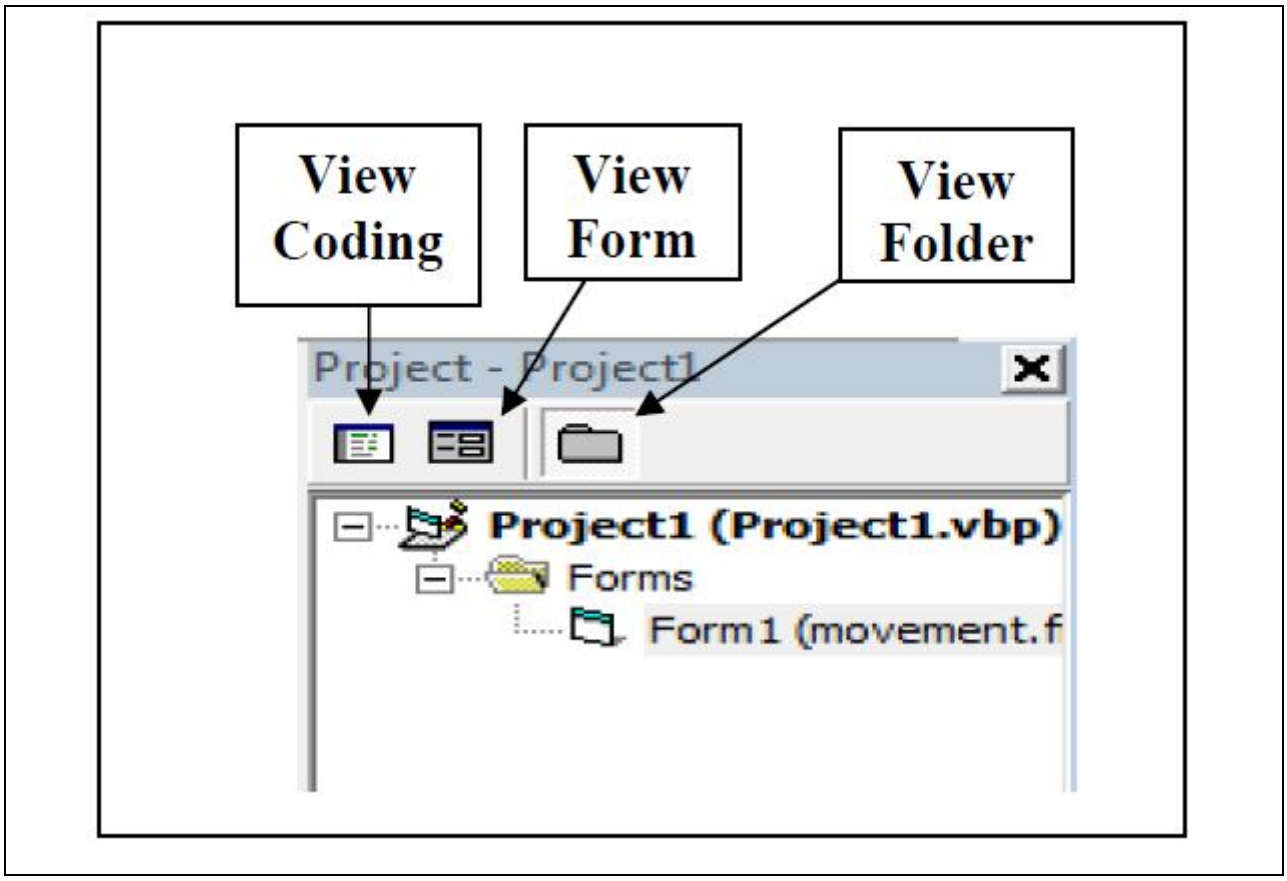

Figure 2.8: Project Explorer

"Toolbox" contains icons representing control used to customize forms which is simple and easy to practice (figure 2.9).

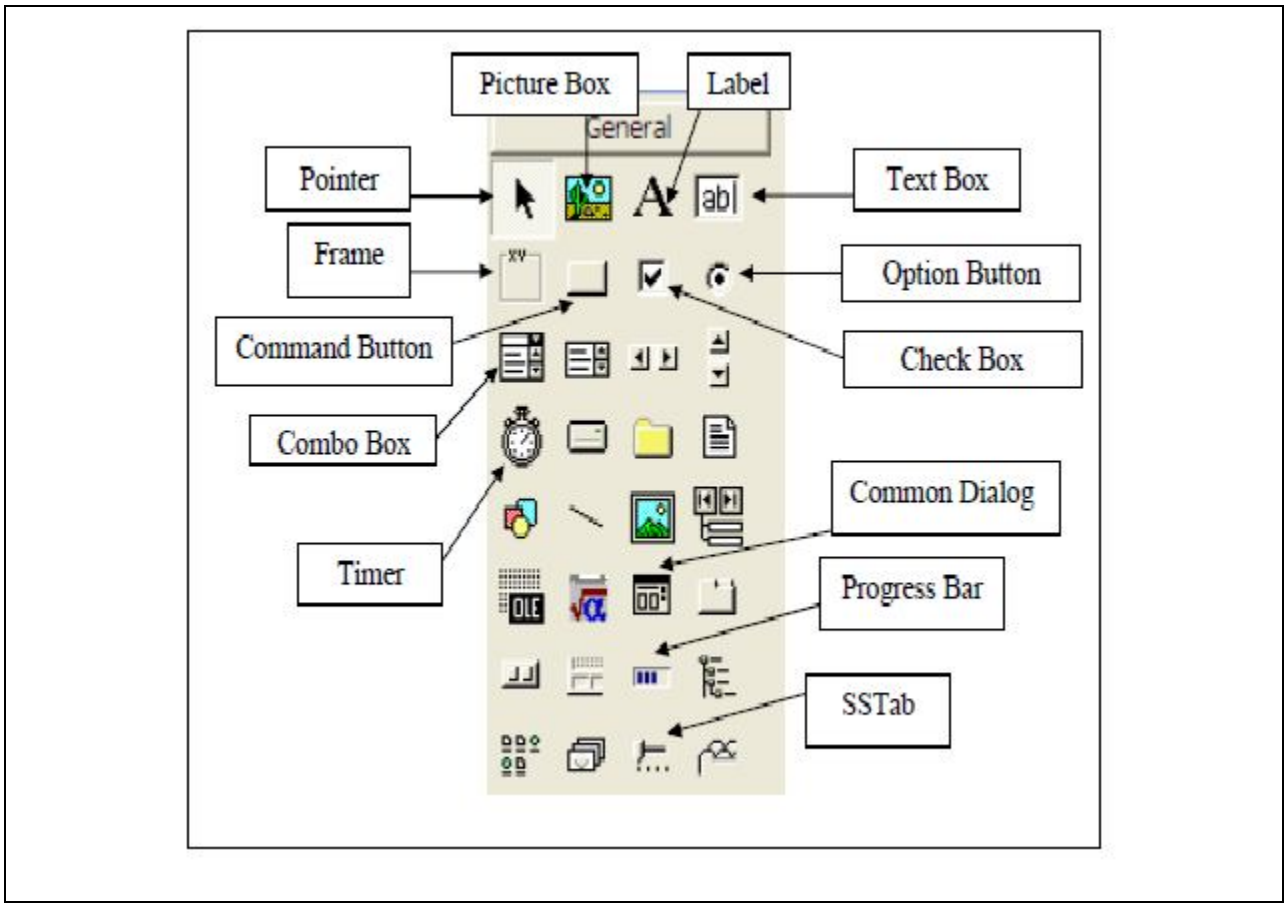

Figure 2.9: Tool Box

"Toolbars" (figure 2.10) us a command for managing the overall program and for developing, maintaining and executing programs with a specific action.

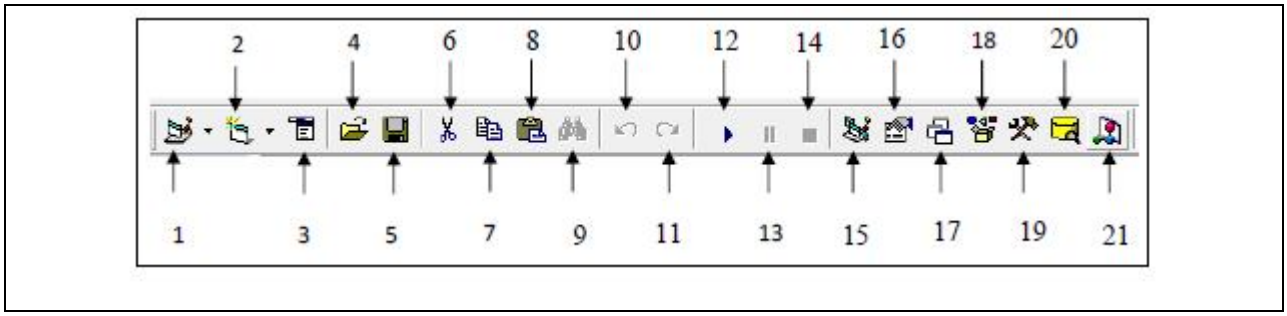

Figure 2.10: Tool Bars

Where:

1 = Add Standard EXE Project

2= Add Form

3= Menu Editor

4= Open project

5= Save Project

6= Cut

7= Copy

8= Paste

9= Find

10= Undo

11= Redo

12= Start/Run Project

13= Break

14= End

15= Project Explorer

16= Properties Window

17= From Layout Window

18= Object Browser

19= Toolbox

20= Data View Window

21= Visual Component Manage

"From" is an interface for user to key in the input in Visual Basic and coding is a programming language in term of scientific and mathematical equation for user to communicate with the program and working under a particular order or command. “Window Properties" is useful for user to make any changes or adjustments to any components in the form such as Name, Form color, and Font Size. "Window from Layout" is use to move or set the position of every Form every time it been display.

VB programmers make user interfaces by drawing controls and other components onto forms. The programmer then adds code to respond to user interactions with the controls known as events. The code can trigger events and execute procedures by run some algorithm based on the values entered in some control to get the output data.

2.8 Flexible Pavement Thickness Design Software

Nowadays, there was various type of Flexible Pavement Thickness Design Software is available in the market and very easy to use and can be applies directly in the computer, laptop or PDA phone such as:

- DNPS 86, developed by American Association of State Highway and Transportation Official (AASHTO).
- FPS-19, developed by Texas Department of Transportation's.
- STREETPAVE, developed by American Concrete Pavement Association.

- FAARFIELD (Design Software for Airport Pavement Thickness).
- SW-1, developed by Asphalt Institute.

In this study, the flexible pavement thickness Design software that been discuss are 86 and 19 to increase the understanding in the development of flexible pavement thickness Design software.

2.8.1 DNPS 86:

The objective of this software is to design a flexible pavement's layers thickness using DNPS 86 program. DNPS 86 software was developed by American Association of State Highway and Transportation Official (AASHTO) U.S.A in late 1950's and early 1990's.

The method of solution use in DNPS 86 software is based on AASHTO guide for design of pavement structure, 1986.DNPS 86 is a user-friendly program where the users just follow the direction of each display screen and key in the requested input and parameters (Figure 2.11). The output can be obtained is the required thickness of each layer including economic cost analysis.

The DNPS 86 pavement design computer is also use to produce a minimum-cost combination of pavement layer thickness. The DNPS 86 program has been made a subroutine of the optimization program ongoing changes being made to DNPS 86 by others can be easily accommodated.

The optimization program DNPS 86 then obtains the minimum-cost design, with corresponding layer thicknesses. Numerical examples illustrate the savings in design time and in equivalent first cost of resulting pavement made possible by using this optimization program.

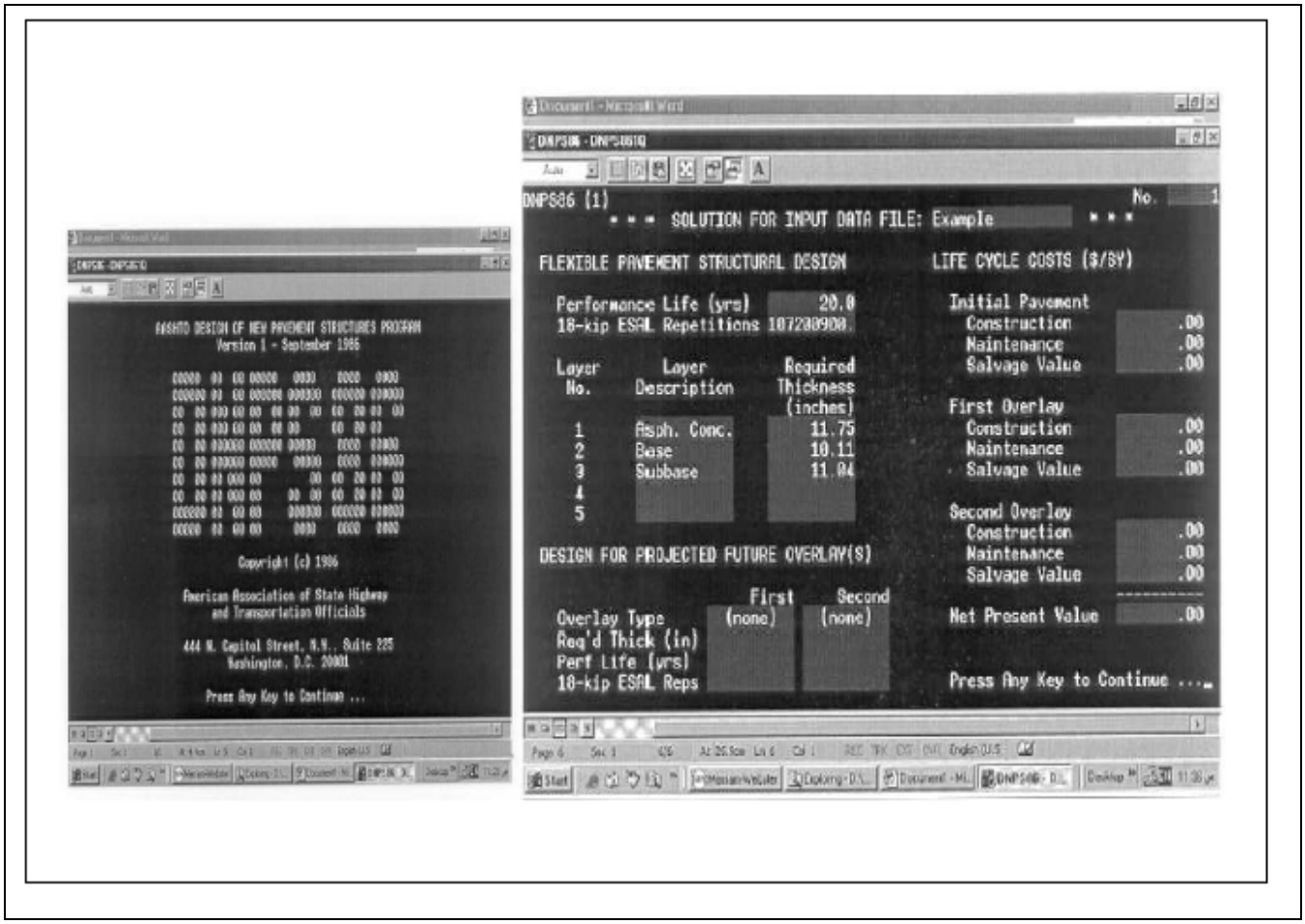

Figure 2.11: Display of DNPS86 Pavement Design Computer Program

2.8.2 FPS-19

EPS 19 is the approved flexible pavement thickness design system developed by Texas Department of Transportation's. Several enhancements have been made to improve this system, including (Tom Scullion, Texas Transportation Institute):

- Transferring EPS 19 to the windows platform (Figure 2.12).
- Provide a thickness checking system according to current Texas Triaxial system.
- Computational of stress and strain subsystem to estimated classical fatigue and rutting for the designed pavement.
- Incorporating an extensive and advance online help system.

The method of solution use in FPS 19 software is based on mechanistic empirical pavement design procedures. The new procedures make analysis simpler and provide designers with many options to crosscheck their design other structural design systems.

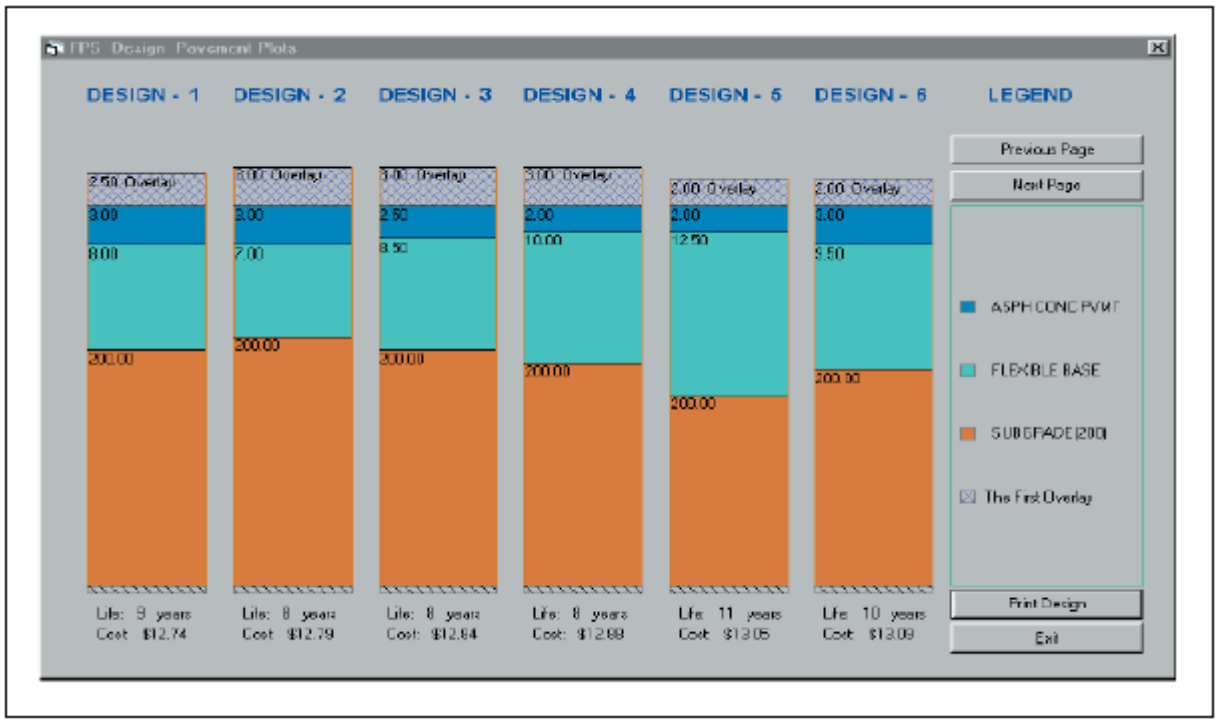

Figure 2.12: Display of Feasible Pavement thickness Design by using FSB 19