Chapter3

Methodology

3.1 Introduction

Methodology is a very important part in a research or study, where it was represented the overall research method to ensure the research will be successful carry out. This chapter will be review on the general framework of the software development, design stage of flexible pavement (AASHTO & Road Note 31), swelling consideration, and determination of structural layer thickness and overview of design stage of software development.

3.2 General Framework of the Software Development

In the flexible pavement design system, the design process for either of the two design modes (new/reconstruction or overlay) was a six parts process that illustrated in Figure 3.1. From the development of software designed, the resulting model may be far from replicating all the important components of pavement design with the error in assumption and simplification was made. Therefore, the development of this software should be investigated to ensure the satisfactory of the result represented before the software confidently used.

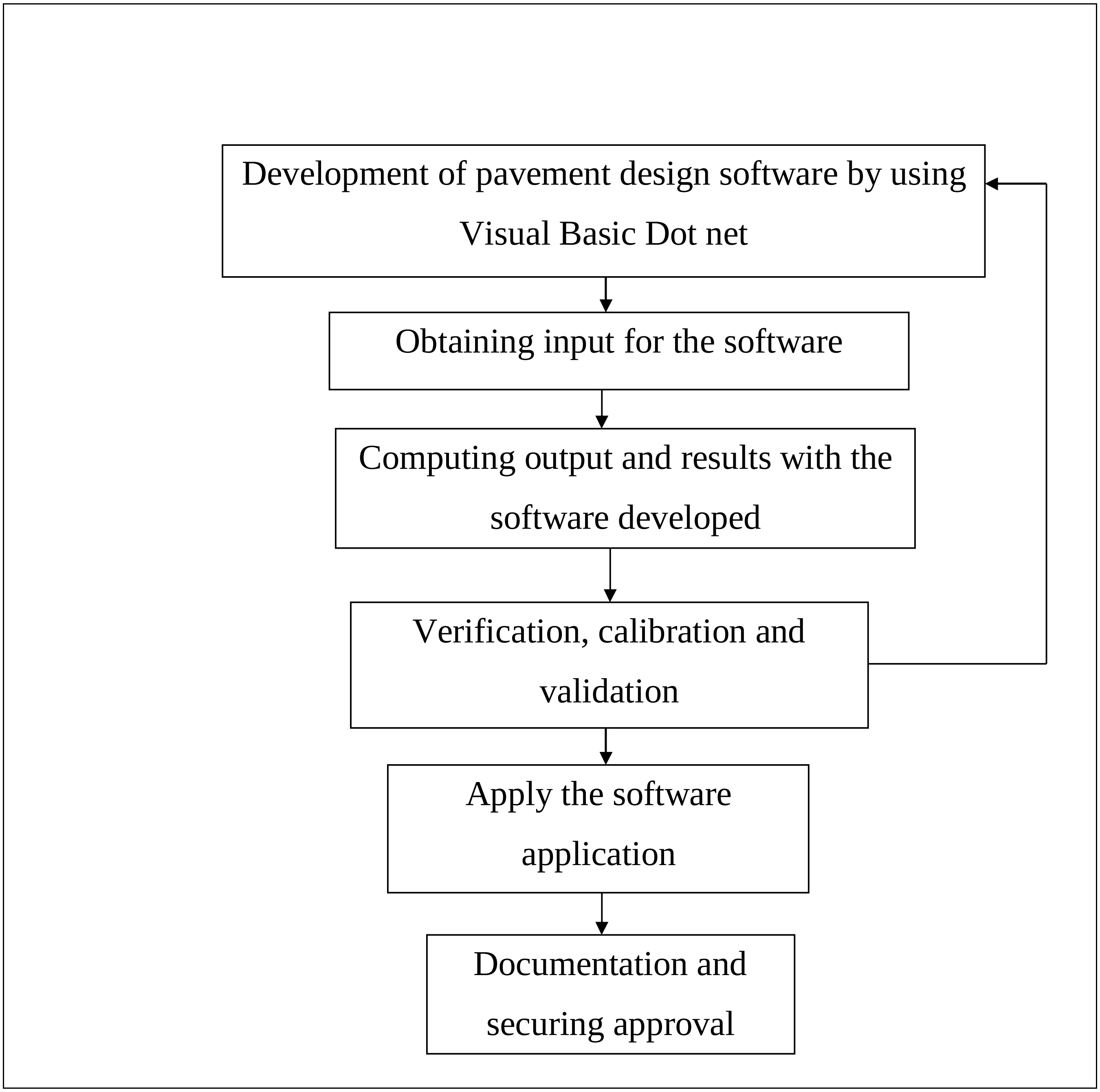


Figure 3.1: Framework of the Software Development

As an overview, the pavement design software been developed by using Visual Basic Dot net computer program languages. The inputs data were act as important element to be read by the program and the design computing output will be done through the Visual Basic computer program. The detail of input parameter were been discussed in section design stage (Section 3.3).

Verification is a procedure for establish the accuracy of the computer program. Verification process is used to examine and test the software whether can perform and behaves simulated accordance with the real accurate result. This process were involved the examining and the translation of the original pavement design conceptual into a Visual Basic Dot net computer program.

Against, to ensure the software developed was correctly presented and verified checking on any incorrect of calculation stage to minimize the possibility of calculation error. Design of Flexible Pavement Structures Model calibration is a process to compare the model output with the guideline or manual calculation practice. In this process, the incorrect parameter value were been adjusted to provide a better quality and accurate parameter value. Before applying the proposed software to real world problems, it was necessary to check for any inconsistency in the software behavior and executed logic through validation process.

Validation is important to test the performance of the software to match its output with actual design result. This was done through a number of test runs to ensure the software developed are stable and can be trusted.

Finally, the documentation and securing approval are important elements to record and store the important result as a reference in the future.

3.3 Design Stage of Flexible Pavement

In this study, the design of flexible pavement is based on AASTHO guide for "Design of Pavement Structure" published by American Association of stage highway and transportation officials, 1993 and Road Note 31 published by Transport Research Laboratory (TRL), 1993. In the design stage, review will be focus on the general equation of flexible pavement design including the all the important parameters, determination of structural layer thickness and layout of structural layer thickness for both methods as an output of design process in report file.

3.4 Overview of AASHTO Design Stage

As an overview of design stage of software development, this study were focus to three main parts that need to be done as input, design stage and output (Figure 3.2). Firstly we define the input data of Predicted number of 18-kip ESAL (W18), standard normal deviate (ZR), standard error (So), design serviceability index (ΔPSI) and subgrade resilient modulus(MR) as the main input data file into Visual Basic Programming for design stage. In the design stage, consideration is focus on general flexible pavement Equation 3.1, and determination of structural layer thickness by using Visual Basic application. Finally, the output of software was represented in report summary file and layout of structural thickness for flexible pavement.

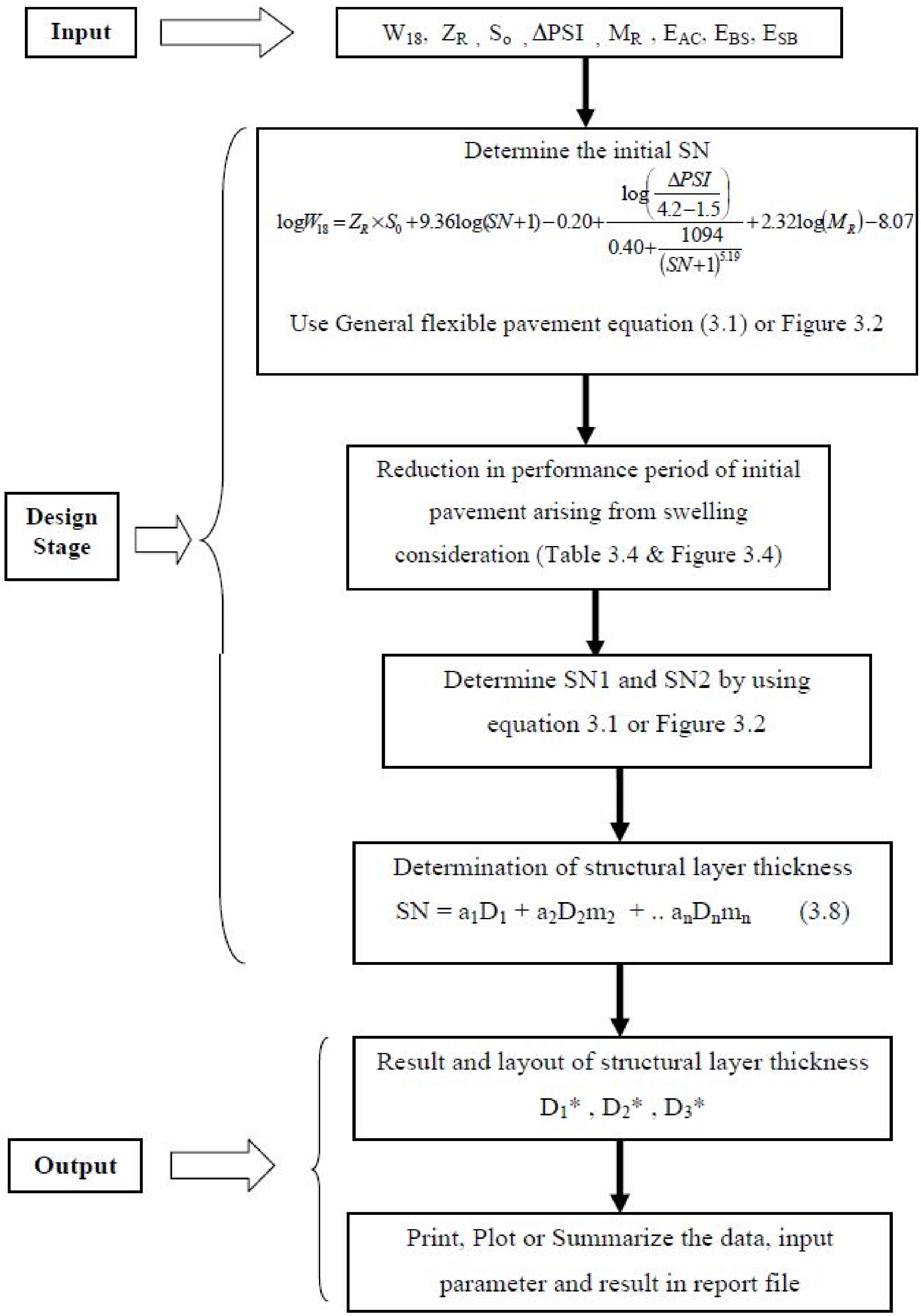


Figure 3.2: Overview of design stage of software program

3.4.1 General Equation of Flexible Pavement AASHTO Design

In AASHTO guide design of pavement structure, the general flexible pavement equation show as below is the common use in design stage.

$$\log_{10} W18 =$$

$$ZR \times S0 + 9.36 \log_{10}(SN + 1) - 0.20 + \frac{\log_{10}[\frac{\nabla PSI}{4.2-1.5}]}{0.40+\frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10} MR - 8.07 \quad (3.1)$$

Where:

W18 = Predicted number of 18-kip equivalent single axle load application

Z_R = Standard normal deviate

So = Combined standard error of the traffic prediction and performance prediction

ΔPSI = Difference between the initial design serviceability index, po, and the design terminal serviceability index, pt.

MR = Subgrade resilient modulus (psi)

The general Equation 3.1 was derived from empirical information obtained from AASTHO Road Test. The design Nomographs presented in Figure 3.3 can solve this equation to determine the structural number (SN) for flexible pavement design.

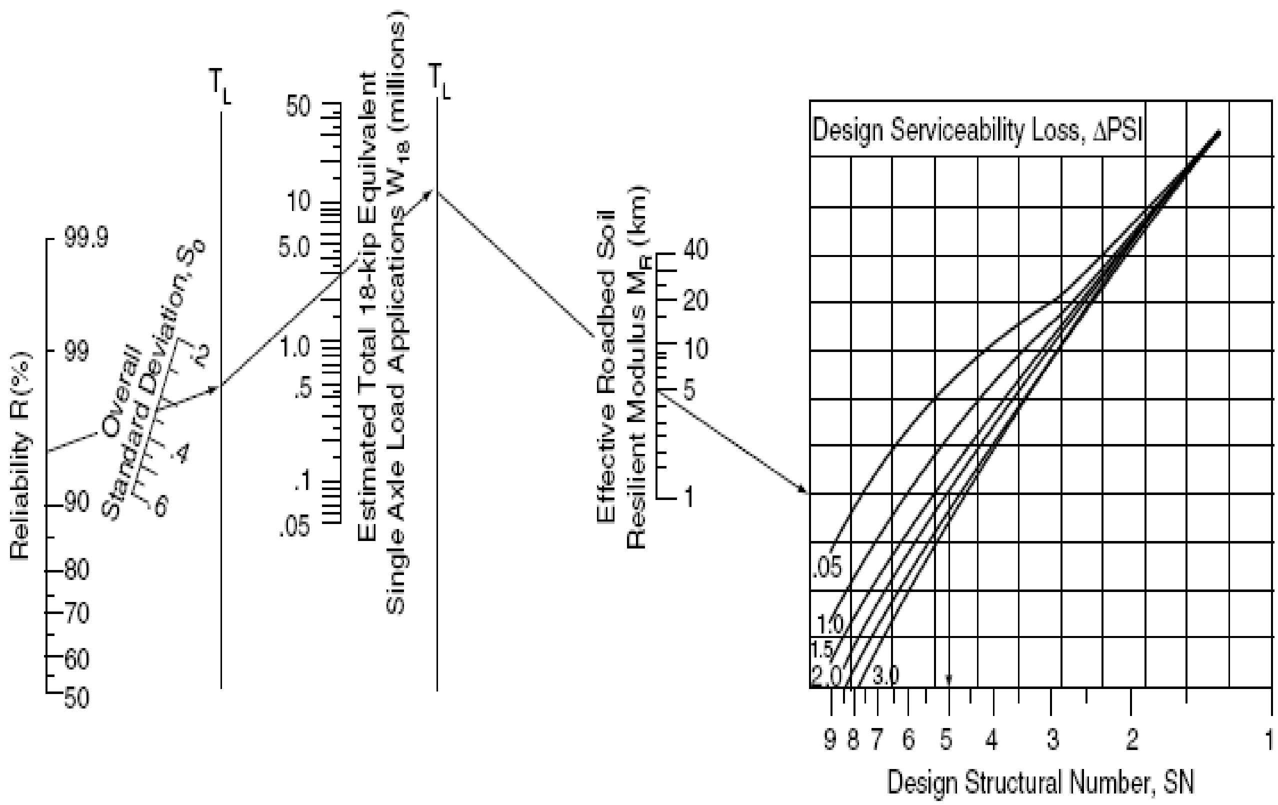


Figure 3.3: Nomo graph for Flexible Pavement Design of AASHTO

3.4.2 Predicted Number of 18-kip ESAL, W18

Normally, the design procedure for traffic volume is based on cumulative expected 18-kip ESAL during the analysis period, w18. W18is known as Predicted number of ESALs over the pavement's life. Thus, the traffic during the first year in the design lane (w18) 18-kip ESAL application can be determining by using the following equation.

w18 (traffic during first year) = DD * DL * w18 (3.2)

Where:

W18 = Cumulative two direction 18-kip ESAL units predicted for a specific section of highway during the analysis period.

DD = Directional distribution factor, express as a ratio, that accounts for the distribution of ESAL unit by direction. (DD = 0.3 to 0.7).

DL = Lane distribution factor, express as a ratio that accounts for distribution for distribution of traffic when two or more lanes are available in one direction. Table 3.1 shows the detail of DL factor.

Table 3.1: D_L factor

Number of lanes in each direction	Percent of 18-kip ESAL in design lane
1	100
2	80-100
3	60-80
4	50-75

Therefore, the commutative 18-kip ESAL traffic can be determined by using equation below:

Commutative 18-kip ESAL, W_{18}=

$$\text{w18 (traffic during first year)}\left(\frac{(1+g)^t-1}{g}\right) \quad (3.3)$$

*Where g is growth rate

3.4.3 Subgrade Resilient Modulus (MR)

Design subgrade resilient modulus MR, Caution must be used when selecting a design resilient modulus. Resilient modulus (MR) values for pavement structure design should normally be based on the properties of the compact layer of roadbed soil. In the flexible pavement design requirements, it may necessary to convert CBR value or R-value information to resilient modulus, MR. Table 3.2 showing Relationship between Marshall and MR According to (K.Saudia. Arabia specifications).

Table 3.2 Relationship between Marshall and MR (K.Saudia. Arabia)

Marshall Stability (lb)	Resilient Modulus (MR) (psi)
500	125000
750	150000
975	200000
1200	250000
1400	300000
1600	350000
1900	400000

The procedures of determination of Effective Subgrade Resilient Modulus (M_{Reff}) are show as the steps below:

1. Obtain MR values (Separate year into time intervals)
2. Compute the relative damage (u), by using Figure 3.3 or using equation below:

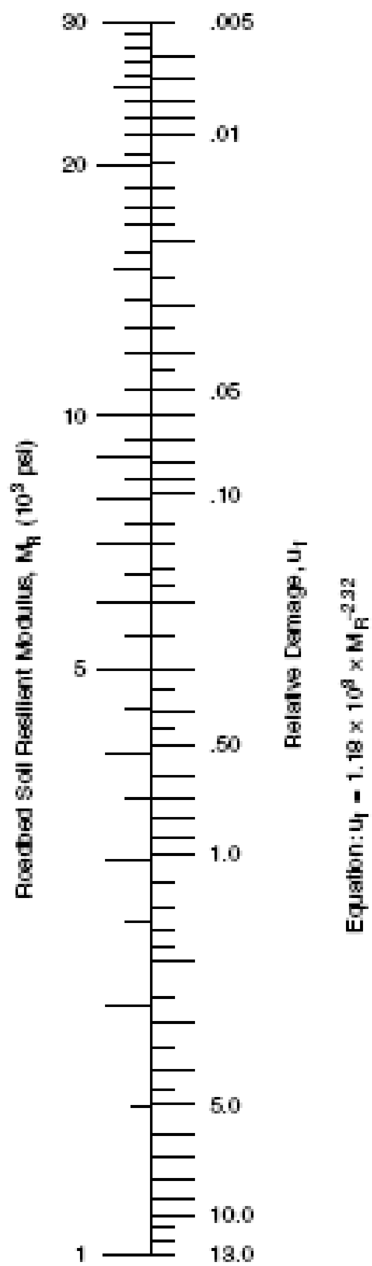
$U_f = 1.18 \text{ X } 10^8 \text{X } M_R^{-2.32}$ (3.4)

3. Compute the average U_f for entire year $= \frac{\sum u}{n}$ (3.5)

Where n is the total number of interval time.

4. Determine effective MR using average uf by using Figure 3.4 or Equation 3.4.

Month	Roadbed Soil Modulus, M_R (psi)	Relative Damage u_f
Jan	20,000	0.01
Feb	20,000	0.01
Mar	2,500	1.51
Apr	4,000	0.51
May	4,000	0.51
June	7,000	0.13
July	7,000	0.13
Aug	7,000	0.13
Sept	7,000	0.13
Oct	7,000	0.13
Nov	4,000	0.51
Dec	20,000	0.01
Summation: Σu_f =		3.72



Average: $\bar{u}_f = \frac{\Sigma u_f}{n} = \frac{3.72}{12} = 0.31$

Effective Roadbed Soil Resilient Modulus, M_R (psi) = 5,000 (corresponds to $\bar{u}_f$)

Figure 3.4: Estimation of effective roadbed soil resilient modulus

3.4.4 Design Serviceability Loss, ΔPSI

The serviceability loss is the difference between the initial serviceability index (po) and the terminal serviceability index (pt).

The term of serviceability is important to measure the performance of design pavement during its service period. The serviceability is express in term of present serviceability index (PSI). Therefore, the change in present serviceability index (ΔPSI) is an important consideration in the flexible pavement design.

According to AASHTO Road Test,the recognized original or initial serviceability (P0) value for a new pavement was 4.7, 4.6 or 4.5. Meanwhile the terminal serviceability index (Pt) of 3.0, 2.5 or 2.0 for major roads, intermediate roads and secondary roads, respectively.

$$\Delta PSI = P0 - Pt \qquad (3.6)$$

Where:

P0 = Original or initial serviceability

Pt = Terminal serviceability index

3.4.5 Reliability, R

In order to decrease the risk of premature deterioration below acceptable level of serviceability, a reliability factor is included in the design process. Increase reliability was obtained by adjustments, which are based on uncertainly in each of design variables. The reliability factor accounts the change variation for both traffic prediction (w18) and pavement performance prediction (W18). In this study, the reliability suggested by AASHTO is show in Table 3.3.

Table 3.3: Suggested level of reliability for various functional classifications

Functional Classification	Recommended Reliability		
	Urban	Rural	WSDOT
Interstate/freeways	85 – 99.9	85 – 99.9	95
Principal arterials	80 – 99	75 – 95	85
Collectors	80 – 95	75 – 95	75
Local	50 – 80	50 – 80	75

Refer to AASHTO Structural Design1993, the relationship between Standard Normal deviate, ZR and reliability, R is show in Table 3.4.

Table 3.4: Relationship between Standard Normal deviate, ZR and reliability, R

Reliability	99.9	99	95	90	85	80	75	70	50
Z_R	-3.090	-2.327	-1.645	-1.282	-1.037	-0.841	-0.674	-0.24	0

3.4.6 Standard Deviation, So

According to AASHTO 1993, the recommended performances predict error developed at the Road Test was 0.35 for flexible pavement. However, the standard deviation must be selected according to the local conditions with 0.35 for no traffic variation and 0.45 with traffic variation.

3.4.7 Determination of Structural Layer Thickness

Structural Number (SN) is an index that is indicative of the total pavement thickness required. It is also known as abstract number expressing structural strength.

Once the design structural number (SN) for the pavement structure is determined from the Nomograph, a set of pavement layer thickness, which when combined will provide the load-carrying capacity corresponding to the design SN can be determined (Figure 3.7). The following equation provides the basis for converting the SN into actual thickness of surfacing, base and sub base:

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 \qquad (3.7)$$

Where:

a_1, = Layer coefficients representative of surface courses (Figure 3.5)

a_2, = Layer coefficients representative of, base courses (Figure 3.6)

a_3 = Layer coefficients representative of sub base courses (Figure 3.7)

D_1, D_2, D_3 = Actual thicknesses (in inches) of surface, base, and sub base courses

m_2, m_3 = Drainage coefficients for base and sub base layers (Table 3.5)

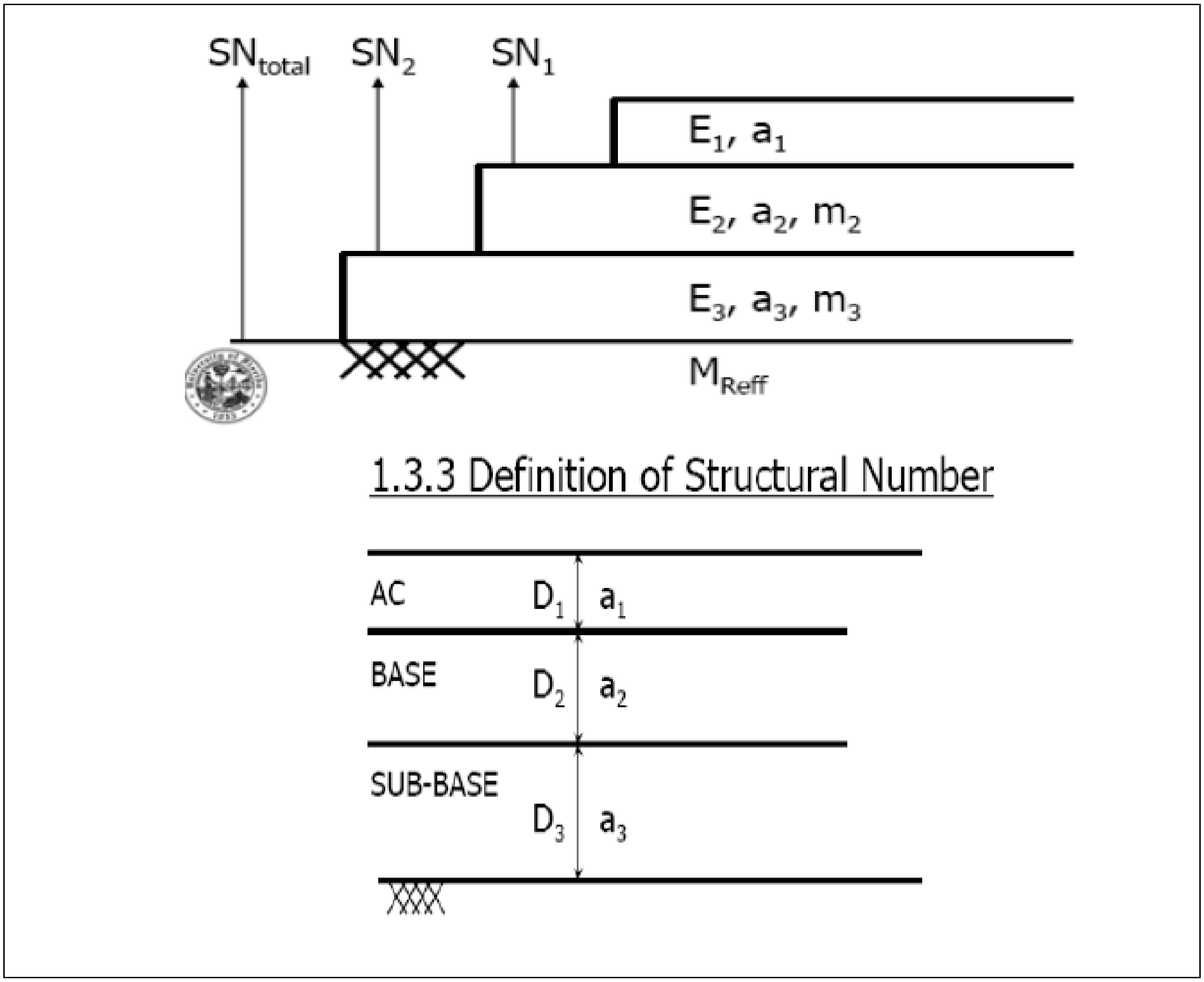


Figure 3.5: Structural Number and Thickness of pavement structure

The general procedures to determine the thickness of pavement corresponding to the design SN are show as below:

1. Using E_2 as the M_R value, determine from Figure 3.3 the structural number SN_1 required to protect the base and compute the thickness of layer 1 by using equation below:

$$D_1^* = \frac{SN_1}{a_1} \qquad (3.8)$$

Check $SN_1^* = a_1 D_1^* \geq SN_1$ OK!

2. Using E_3 as the M_R value, determine from Figure 3.3 the structural number SN_2 required to protect the sub base and compute the thickness of layer 2 by using equation below:

$$D_2^* = \frac{SN_2 - SN_1^*}{a_2 m_2} \qquad (3.9)$$

$SN_2^* = a_2 D_2^*$

Check $SN_1^* + SN_2^* > SN_2$ Ok!

3. Based on the roadbed soil resilient modulus M_{Reff}, determine from Figure 3.3 the total structure number SN_3 require and compute the thickness of layer 3 by using below:

$$D_3* = \frac{SN_3-(SN_1*+SN_2*)}{a_3m_3} \quad (3.10)$$

4. Therefore, the total thickness for pavement structural =

$$D_1*+D_2*+D_3* \quad (3.11)$$

3.4.8 Pavement Layer Material Characteristic

Pavement layer material characteristic is an important input to determine the layer coefficient (a_i) for each particular layer. According to AASHTO 1993, there are three common type of pavement material constituted the individual layers of the structure known as Asphalt concrete surface course (E_{AC}), granular base layers (E_{BS}), and granular sub base layers (E_{SB}).

Therefore, the layer coefficients for a_1, a_2, and a_3 can be determined from Figure 3.8, Figure 3.9 and Figure 3.10 respectively by applying the E_{AC}, E_{BS} and E_{SB} into the figures or using the below equation:

$$a2 = 0.249(\log_{10}E_{BS}) - 0.977 \quad (3.12)$$

$$a3 = 0.277(\log_{10}E_{SB}) - 0.8397 \quad (3.13)$$

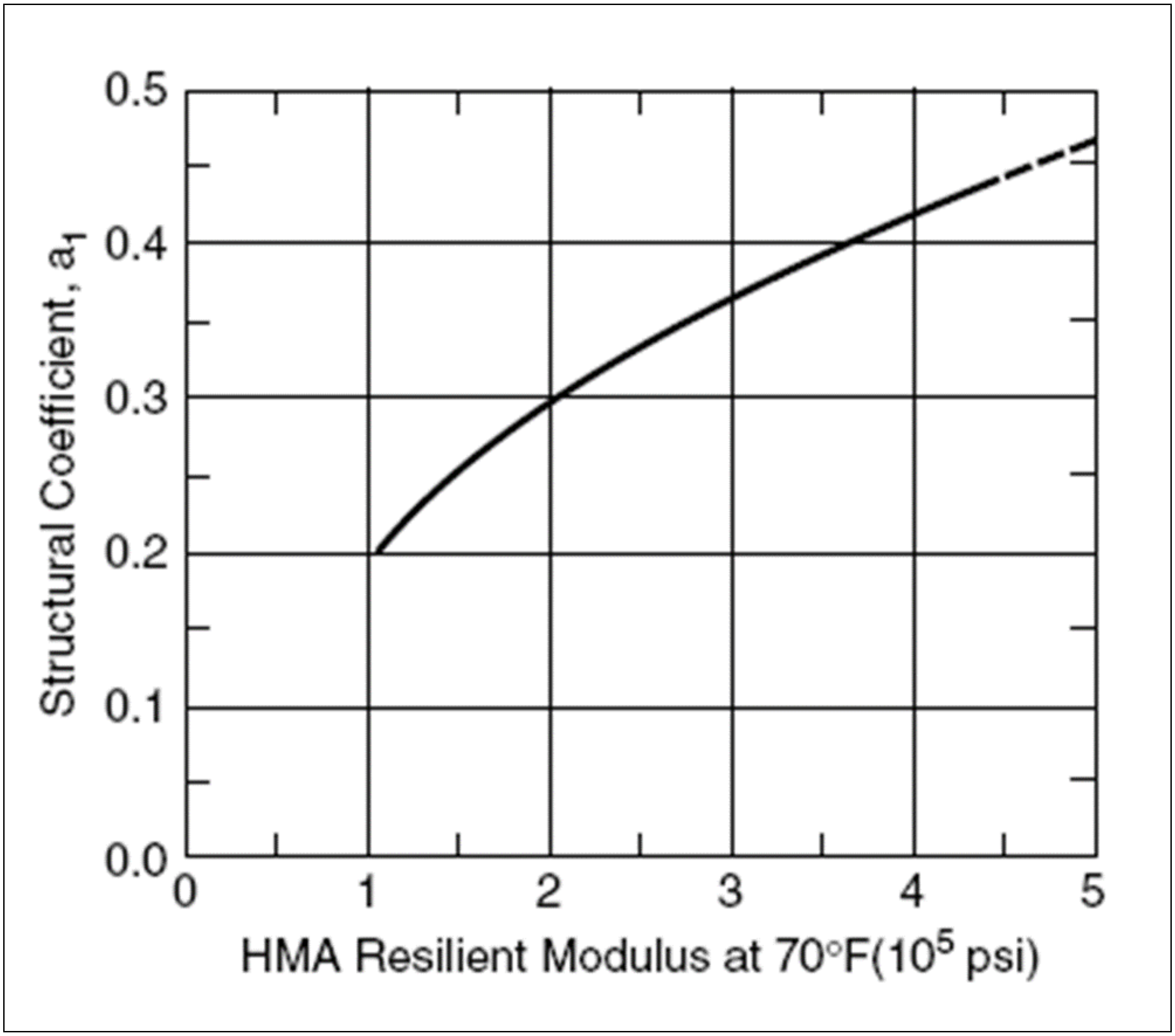


Figure 3.6: Structural layer coefficient (a1) of dense-graded asphalt concrete base

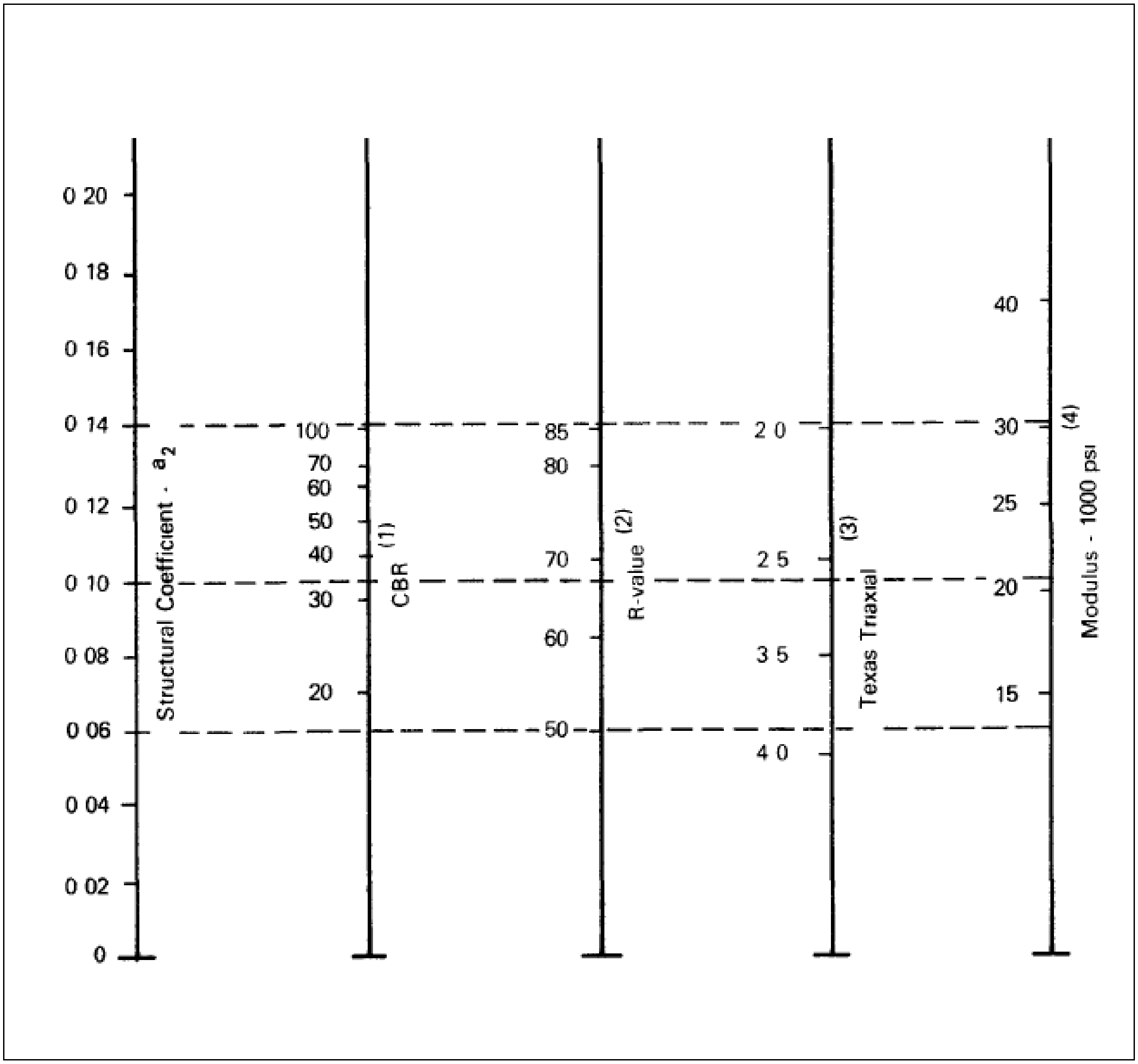


Figure 3.7: Variation in granular Base layer coefficient (a2) with various Base strength parameters.

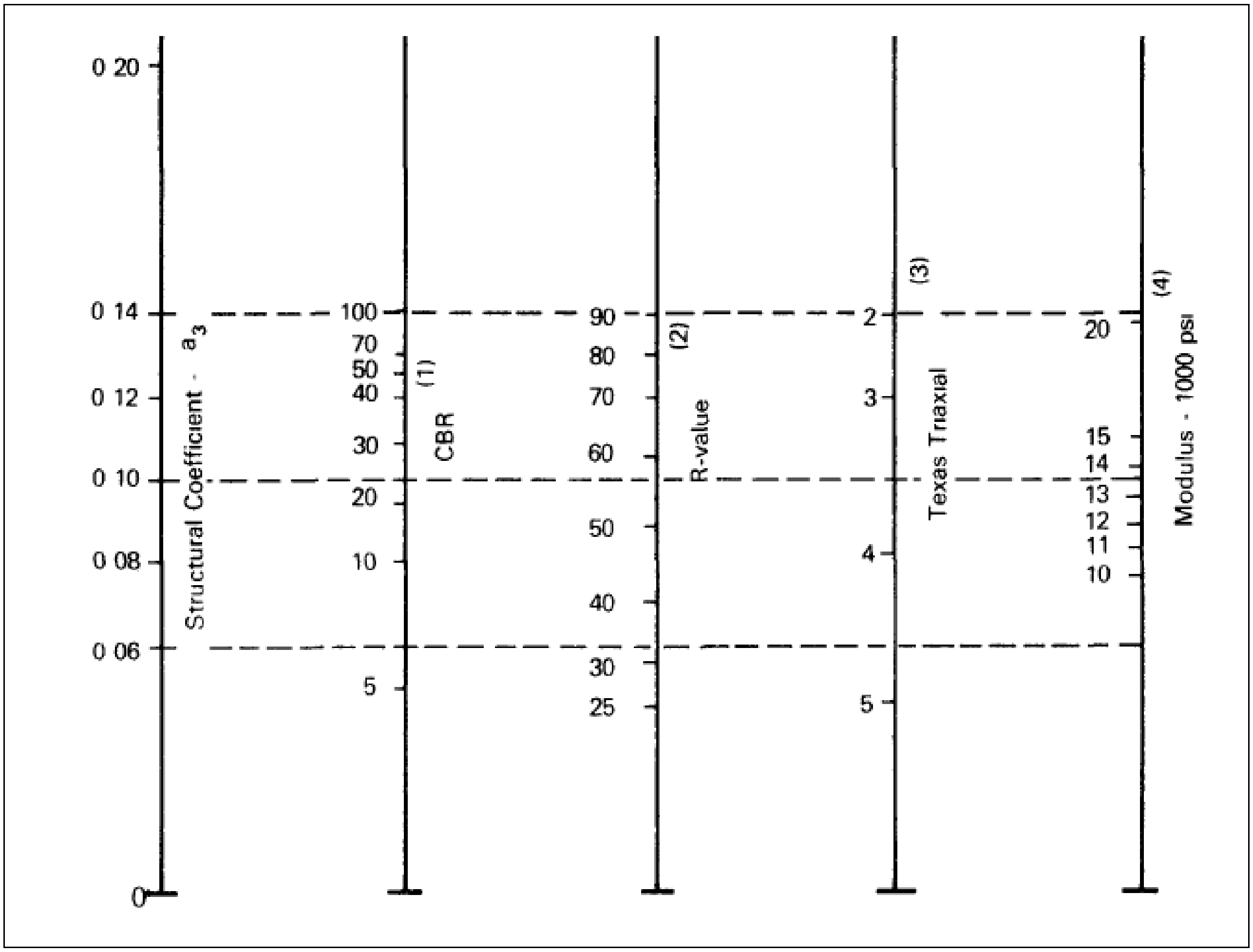


Figure 3.8: Variation in granular sub base layer coefficient (a3) with various sub base strength parameter.

3.4.9 Drainage Coefficient (m_i)

Generally, quick draining layers that almost never saturate can have drainage coefficients as high as 1.4, while slow-draining layers that often saturate can have drainage coefficients as low as 0.40. For most designs, use a value of 1.0. If the quality of drainage is known as well as the period of time and the pavement is exposed to levels approaching saturation. Table 3.5 below show the drainage coefficient of untreated base and sub base material in flexible pavements.

Table3.5: Recommended m_i value for modifying structural layer coefficients of untreated base and sub base material in flexible pavements.

	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation			
Quality of Drainage	Less Than 1%	1-5%	5-25%	Greater Than 25%
Excellent	1 25–1 20	1 20–1 15	1 15–1 10	1 10
Good	1 20–1 15	1 15–1 10	1 10–1 00	1 00
Fair	1 15–1 10	1 10–1 00	1 00–0 90	0 90
Poor	1 10–1 00	1 00–0 90	0 90–0 80	0 80
Very poor	1 00–0 90	0 90–0 80	0 80–0 70	0 70

3.5 Overview of Design Stage for Road Note 31

In overview of design, stage for Road Note 31 was divided to three main parts shows as below:

1. Estimate the amounts of traffic and cumulative number of equivalent standard axles over the design life of the road. The CSA obtained will be used to identify the traffic classes (Table 3.6)
2. Determine the subgrade strength classes from plasticity index and depth of water table (Table 3.8) or based on CBR value (Table 3.7)
3. Select the economic combination of pavement material and thickness from the structural catalogue (Table 3.9) that will meet the satisfactory of pavement service and design life based on T and S values.

Table 3.6: Traffic class

Traffic classes (10^6 esa)	
T1 =	< 0.3
T2 =	0.3 - 0.7
T3 =	0.7 - 1.5
T4 =	1.5 - 3.0
T5 =	3.0 - 6.0
T6 =	6.0 - 10
T7 =	10 - 17
T8 =	17 - 30

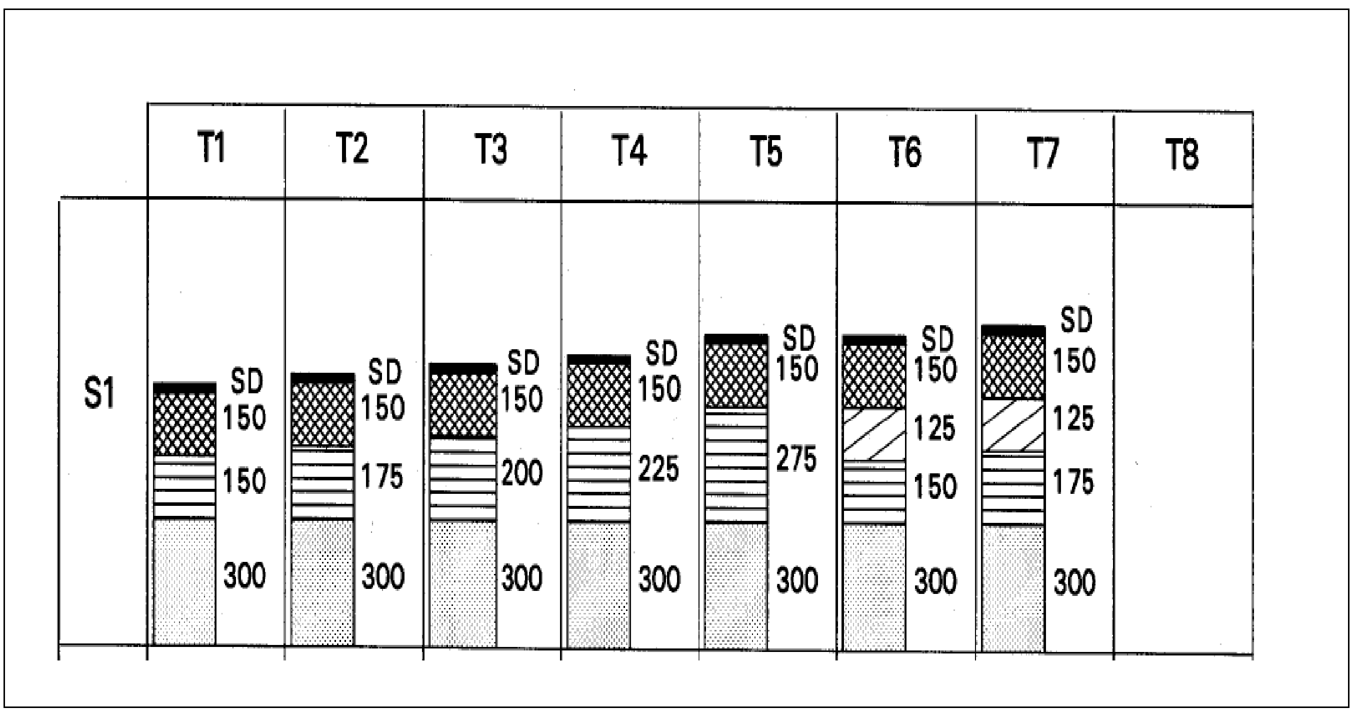
Table 3.7: Subgrade Strength class

Subgrade strength classes (CBR%)	
S1 =	2
S2 =	3 , 4
S3 =	5 - 7
S4 =	8 - 14
S5 =	15 - 29
S6 =	30+

Table 3.8: Subgrade Strength class

Depth of water tablefrom formation (m)	Subgrade Strength class				
	Non-plastic sand	Sandy clay P1=10	Sandy clay P1=20	Silty clay P1=30	Heavy clay P1>40
0.5	S4	S4	S3	S2	S1
1	S5	S4	S3	S2	S1
2	S5	S5	S4	S3	S2
3	S6	S5	S4	S3	S2

Table 3.9: Example of structural catalogue



In the methodology of Road Note 31 design, the input of cumulative traffic loading, subgrade plasticity and depth of water from formation level (moisture supply) was calling from AASHTO design that the user key in previously. Therefore, and Road Note 31 method was sharing the same input with AASHTO method but provided different design results.

3.6 Program Language

In this study, the software development for flexible pavement thickness design were been developed by using application of Visual Basic Dot net programming language. Visual Basic Dot net is a powerful programming language in term of scientific and engineering application solution.

Visual basic Dot net is friendly uses software with a graphical user interface.

Therefore, Visual Basic can represent high attractive graphical and powerful calculation tool that can be used to develop software for flexible pavement thickness design and act as database system to store all the important data and information to be refer and guide in the programming.

Besides that, application of Visual Basic Dot net also is corresponding to the other computer application such as Microsoft Excel and Microsoft Access to share the same characteristic database with each other.

Finally, the result from software developed obtain were been compare with an appropriate and correct example to verify the accuracy of results obtain. Any error or incorrect parameter will be corrected to achieve the actual result of flexible pavement thickness design base on AASHTO and Road Note 31 method.