THE NEW PWD MANUAL ON PAVEMENT DESIGN

Mohd Hizam Harun
Public Works Department, Malaysia.
E-mail: HIZAM@jkr.gov.my

Siti Nur Azzwa Razali
Public Works Department, Malaysia.
E-mail: snAzzwa@jkr.gov.my

ABSTRACT

The current Public Works Department of Malaysia (PWD) Manual on Pavement Design (Arahan Teknik (Jalan) 5/85)[1] is loosely based on the 1981 Asphalt Institute (MS-1) and AASHTO design procedures. However these procedures have undergone several revisions; NCHRP Research Project 20-7 was undertaken, the results of which were used to formulate a substantial revision of the AASHTO Guide for the Design of Pavement Structures which was issued in 1986. Another revision to the AASHTO Guide was published in 1993 (GDPS-4) and further amended in 1998 (GDPS-4S). By comparison, Arahan Teknik (Jalan) 5/85[1] dates back to 1985 and is thus by international standards outdated by several "technical generations". It does not allow designing pavement structures that are either sufficiently durable for current and future traffic, or optimised in terms of function and user safety. PWD has therefore conducted a study in this area, the result of which is a revised and substantially upgraded pavement design manual which incorporates performance based stress and strain analysis and mechanistic material characterisation. The Manual provides the users with a uniform process of designing pavement structures for all classes of traffic. It is based on proven, validated pavement design technologies; it builds on past PWD practice and experience and on design methodologies that have been successfully used in other countries over the last twenty years. This manual recommends design approach which combines improved design development data and mechanistic methods of analysis into a single tool that is presented in the form of catalogue of pre-designed pavement structures.

1.0 INTRODUCTION

The current Manual on Pavement Design (Arahan Teknik (Jalan) 5/85)[1] of the Public Works Department, Malaysia (PWD) is loosely based on the 1981 Asphalt Institute (MS-1) and AASHTO design procedures. However these procedures have undergone several revisions; NCHRP Research Project 20-7 was undertaken, the results of which were used to formulate a substantial revision of the AASHTO Guide for the Design of Pavement Structures which was issued in 1986. Another revision to the AASHTO Guide was published in 1993 (GDPS-4) and further amended in 1998 (GDPS-4S). By comparison, Arahan Teknik (Jalan) 5/85[1] dates back to 1985 and is thus by international standards outdated by several "technical generations".

The Manual does not allow designing pavement structures that are either sufficiently durable for current and future highway traffic, or optimised in terms of function and user safety. PWD has therefore conducted a study in this area, a result of which is a revised and substantially upgraded pavement design manual which incorporates performance based stress and strain analysis and mechanistic material characterisation. The Manual is presented in the form of catalogue of pavement structures with traffic volume and sub-grade strength as primary input.

This Manual contains procedures for the design of the following pavement structures;

- New flexible and semi-flexible pavements containing one or more bound layers.
- New flexible pavements for low volume roads, consisting of unbound or cement stabilised granular materials capped with a thin bituminous surface treatment.
- New flexible and semi-flexible heavy duty pavements for severe loading conditions.
- Rehabilitation of rigid or flexible pavements through partial reconstruction or overlay with one or more bituminous layers, through hot-in-place recycling (HIPR) with or without an overlay, or cold-in-place recycling (CIPR) followed by bituminous overlay.

For the purpose of this Manual, flexible pavements shall consist of one or more bituminous paving materials and a bituminous or granular road base supported by a granular sub-base. Semi-flexible pavements shall include cement-bound or similarly stabilised base course consisting either of plant-mixed aggregate stabilised with cement, fly-ash or lime or of an in-situ recycled and stabilised layer using CIPR technique, incorporating additives such as bituminous emulsion, foamed bitumen or cement. This Manual does NOT contain information related to the design of new rigid pavement structures.

2.0 PAVEMENT DESIGN METHODOLOGY

The design procedure used in this Manual is based on traditional concepts of pavement design, which is based on the assumption that the following two strains are critical to pavement performance;

- Vertical strain ε_z on top of the sub-grade
- Horizontal strain ε_t at the bottom of the lowest bound pavement course

In the design process, type and course thickness of paving materials are selected to ensure that the above strains remain within an acceptable range. Vertical sub-grade strain is adopted as a design criterion to control accumulation of permanent deformation of the sub-grade. Sub-grade deformation (strain) is primarily a function of sub-grade stiffness and strength, traffic (design load and cumulative traffic volume over design period), and the thickness and stiffness of the pavement structure above the sub-grade. Horizontal strain at the bottom of the bound layer (bituminous or cement treated material) is used to control fatigue damage due to repeated traffic loads. Both of these strain values are expressed as a function of traffic volume. The allowable design strain is that which occurs under a single pass of an Equivalent Standard Axle Load (ESAL). Allowable strain values decrease with increasing traffic volume; strain caused by a single pass of the design wheel load must be smaller for a pavement designed for high volumes of traffic than for low traffic volumes.

2.1 Determination of Design Traffic

The Equivalent Standard Axle Load (ESAL) used in this Manual is 80 kN, which corresponds to the standard axle load used in the AASHTO pavement design procedure. Traffic volume is calculated from a known or estimated volume of commercial vehicles (CV) and axle load spectrum. Axle loads of passenger cars are too low to cause significant pavement distress; therefore, traffic counts and axle load spectra used for pavement design are based on the volume and type of commercial vehicles.

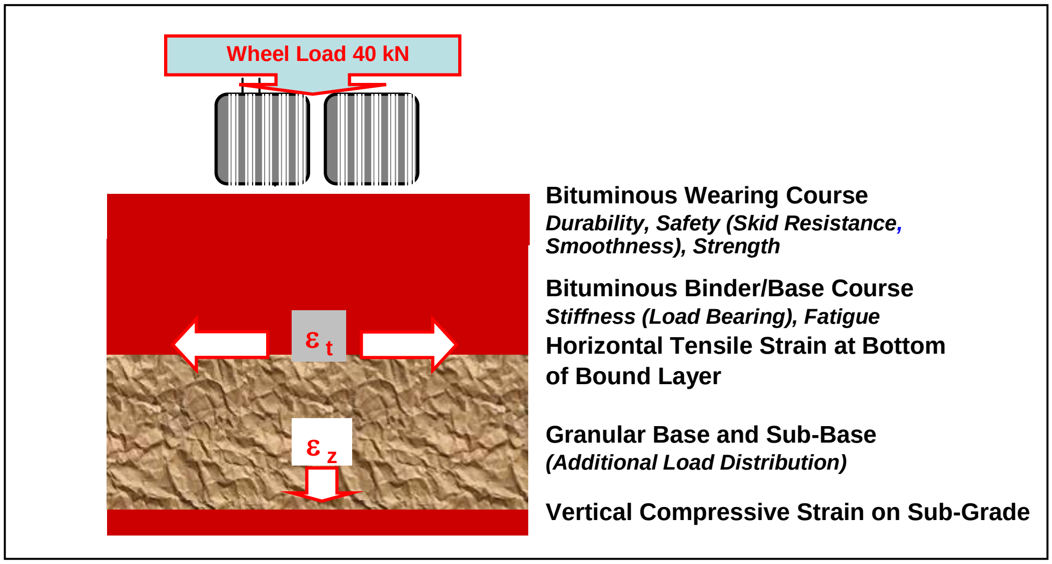

Figure 1: Components of a Typical Flexible Pavement Structure

Traffic data that are considered in this Manual include;

- Number of commercial vehicles during Year 1 of Design Period, which is the expected year of completion of construction.
- Vehicle class and axle load distribution.
- Directional and lane distribution factors.
- Tyre characteristics and inflation pressure.
- Traffic growth factors.

Three types of raw traffic data are typically collected and entered into a data base; vehicle counts, vehicle classification, and load data. Based on current Malaysian practice of traffic characterisation, two types of data are available for structural pavement design;

- Traffic volume and percent commercial vehicles from the JKR national traffic data base (administered by the Highway Planning Unit or HPU).
- Axle load studies, which provide information about the axle load spectrum for selected types of roads and highways in Malaysia.
- Axle load studies provide information about the type of commercial vehicles and axle loads for a specific road section. Axle configurations and corresponding load equivalence factors (LEF) used as basis for this Manual are shown in **Table 1**.

For pavement design purposes, mixed traffic (axle loads and axle groups) is converted into the number of ESAL repetitions by using load factors. The structural design of a pavement is then based on the total number of ESAL passes over the design period. Load factors can be determined from theoretically calculated or experimentally measured truck and axle loads. Information from axle load studies carried out in Malaysia and from legal loads in Malaysia (*Maximum Permissible Gross Vehicle and Axle Loads, RTA 1987, Weight Restriction Order 2003)* have been used as basis for calculating commercial vehicle load factors for traffic classes monitored by HPU.

Table 1: Axle Configuration and Vehicle Load Factors (VLF) based on Traffic Categories used by HPU

Vehicle		Basis for Calculating VLF		Vehicle Load Factor (VLF)
HPU Class Designation	**Class**	**LEF**	**TAF**	
▪ Cars and Taxis	C	<0.01	N/A	0
▪ Small Trucks and Vans (2 Axles)	CV1	0.1	1.0	0.1
▪ Large Trucks (2 to 4 Axles)	CV2	4.5 2.4 3.1	1.4	4.0 (3.2 to 5.2)
▪ Articulated Trucks (3 or more Axles)	CV3	2.6 4.2 2.9 4.1	1.4	4.4 (3.9 to 5.8)
▪ Buses (2 or 3 Axles)	CV4	1.5	1.2	1.8
▪ Motorcycles	MC		N/A	0
▪ Commercial Traffic (Mixed)	CV %			3.5

Note: Axle load studies provide the most reliable basis for calculating ESAL; axle load studies should be carried out and used whenever feasible.

In the absence of an axle load study, **Table 1a** below shall be used as a guide.

Table 1a: Guide for Load Equivalence Factor without Axle Load Study

Percentage of Selected Commercial Vehicles*	0 – 15%		16 – 50%	51 – 100%
Type of Road **Load Equivalence Factor**	Local 1.2	Trunk 2.0	3.0	3.7

* Selected commercial vehicles refer to those carrying timber and quarry materials.

Table 1b: Tyre Pressure Adjustment Factor (TAF)

Combined Thickness of Bituminous Layers (cm)	**Tyre Inflation Pressure (kPa)**		
	480	**700**	**1050**
10	1.2	1.8	4.0
15	1.0	1.5	2.3
20	1.0	1.3	1.5
22	1.0	1.2	1.4
26	1.0	1.1	1.3

The following permissible gross vehicle weights (MGVW) and maximum axle loads (MAL) in accordance with *List 1* (Peninsular Malaysia) of the *Road Transport Act, Weight Restrictions Order 2003*, were used as basis for calculating Vehicle Load Factors (VLF) shown in **Table 1**.

- Axle Loads:
  - Maximum Single Axle (4 Wheels): 12 tonnes
  - Maximum Tandem Axle: 19 tonnes
  - Maximum Tridem Axle: 21 tonnes
- Maximum Permissible Gross Vehicle Weights (RIGID Vehicles):
  - 2-Axle: 18 tons
  - 3-Axle: 26 tons
  - 4-Axle: 33 tons
- Maximum Permissible Gross Vehicle Weights (ARTICULATED Vehicles):
  - 3-Axle: 30 tons
  - 4-Axle: 37 tons
  - 5-Axle: 40 tons
  - 6-Axle: 44 tons

2.2 Design Procedure

The procedure for calculating the **Traffic Category** to be used as design input (number of 80 kN ESALs over Design Period, see **Table 3**), is as follows;

1. From traffic counts for the project under consideration (information provided by **HPU** for the past 5 or more years), determine;
   a. Initial **Average Daily Traffic in one direction (ADT);** the average should be based on a minimum of 3 days, 24 hours per day. If traffic count covers a time period of 06:00 to 22:00 hours, multiply the traffic count reported by HPU with a factor of 1.2.
   b. Percentage of **Commercial Vehicles (CV)** with an un-laden weight of more than 1.5 tons (P_{CV}) and break-down into vehicle categories (shown in **Table 1**).
   c. Average Annual **Traffic Growth Factor (r)** for CV.
2. Determine the following information from the geometric design of the road for which the structural pavement design is carried out;
   a. Number of lanes.
   b. Terrain conditions (flat; rolling; mountainous).
3. Select **Design Period** (20 years for Traffic Categories T 3 to T 5 and minimum 10 years for Traffic Categories T 1 and T 2).
   Note: *Estimate Traffic Category based on conceptual design and refine, if needed, during pavement design process.*
4. Calculate the **Design Traffic (Number of ESALs) for the Design Lane and <u>Base Year Y_1</u> (First Year of Design Period)** using the following formula;

$$ESAL_{Y1} = ADT \times 365 \times P_{CV} \times VLF \times L \times T \qquad (1)$$

where;
$ESAL_{Y1}$ = Number of ESALs for the Base Year (Design Lane)
ADT = Average Daily Traffic

P_{CV} = Percentage of CV (Un-Laden Weight > 1.5 tons)
VLF = Vehicle Load (Equivalence) Factor (including Tire Factor)
L = Lane Distribution Factor (refer to **Table 1c**)
T = Terrain Factor (refer to **Table 1d**)

VLF in *Equation (1)* is 3.5 (weighted average distribution of commercial traffic and axle loads. If site specific distribution of traffic by vehicle type is available, *Equation (1)* shall be refined as follows;

$$ESAL_{YI} = [ADT_{VCI} \times VLF_1 \times ADT_{VC2} \times VLF_2 + \ldots + ADT_{VC4} \times VLF_4] \times 365 \times L \times T \quad (2)$$

where;
ADT_{VC2}, etc = Average Daily Number of Vehicles in each Vehicle Class
VLF_2, etc = Vehicle Load Factor of applicable vehicle class
Other symbols as shown for *Equation (1).* Other **design input factors** used in *Equations (1)* and *(2)* are provided in **Tables 1c** and **1d** below.

Table 1c: Lane Distribution Factors

Number of Lanes (in ONE direction)	Lane Distribution Factor, L
One	1.0
Two	0.9
Three or more	0.7

Note: Traffic in the primary design lane (one direction) decreases with increasing number of lanes.

The Terrain Factor, T that shall be used in the determination of the design traffic volume (ESAL) is shown in **Table 1d** below.

Table 1d: Terrain Factors

Type of Terrain	Terrain Factor, T
Flat	1.0
Rolling	1.1
Mountainous/Steep	1.3

Note: As terrain changes from flat to mountainous topography, the percentage of road sections with steep slopes and with curves increases, thus increasing stresses and strains in pavement structures due to breaking, acceleration and cornering of commercial vehicles.

5. Calculate the **Design Traffic (Number of ESALs) for the Design Period (Design Life in Years)** using the following formula;

$$\text{Design Traffic } ESAL_{DES} = ESAL_{Y1} \times [(1 + r)^n - 1]/r \quad (3)$$

where;

$ESAL_{DES}$ = Design Traffic for the Design Lane in one Direction (determines the Traffic Category used as Basis for selecting a Pavement Structure from the Catalogue)

$ESAL_{Y1}$ = Number of ESALs for the Base Year (Equation 1 or 2)

r = Annual Traffic Growth Factor for Design Period

n = Number of Years in Design Period

Alternatively, the following simplified *Equation* (3a) shall be used in conjunction with the Total Growth Factor shown in **Table 2** below.

$$\textit{Design Traffic } ESAL_{DES} = ESAL_{Y1} \times TGF \qquad (3a)$$

Table 2: Total Growth Factors (TGF)

Design Period (Years)	**Annual Growth Rate (%)**					
	2	**3**	**4**	**5**	**6**	**7**
5	5.20	5.31	5.42	5.53	5.64	5.75
10	10.95	11.46	12.01	12.58	13.18	13.82
15	17.29	18.60	20.02	21.58	23.28	25.13
20	24.30	26.87	29.78	33.06	36.79	41.00
25	32.03	36.46	41.65	47.73	54.86	63.25
30	40.57	47.58	56.08	66.44	79.06	94.46

For the purpose of this Manual, predicted traffic expressed as number of ESALs over the design period is classified into the following traffic categories (**Table 3**).

Table 3: Traffic Categories used in this Manual (ESAL = 80 kN)

Traffic Category	**Design Traffic (ESAL x 10^6)**	**Probability (Percentile) Applied to Properties of Sub-Grade Materials**
T 1	≤ 1.0	≥ 60%
T 2	1.1 to 2.0	≥ 70%
T 3	2.1 to 10.0	≥ 85%
T 4	10.1 to 30.0	≥ 85%
T 5	> 30.0	≥ 85%

Note: Whenever feasible, statistical analysis shall be used to evaluate laboratory or field test results for use as input for pavement design (sub-grade, sub-base, road base and bituminous courses). The above probability values shall be applied to material strength and stiffness values as follows;

Design Input Value = Mean – (Normal Deviate x Standard Deviation)

For normal distribution and single-tailed analysis, the following Normal Deviate values shall apply;

60% Probability: Mean - 0.253 x STD
70% Probability: Mean - 0.525 x STD
85% Probability: Mean - 1.000 x STD

2.3 Properties of Sub-Grade

Sub-grade strength is one of the most important factors in determining pavement thickness, composition of layers and overall pavement performance. The magnitude and consistency of support that is provided by the sub-grade is dependent on soil type, density and moisture conditions during construction and changes that may occur over the service life of a pavement.

For pavement design purposes, several parameters shall be used to categorise sub-grade support. Traditionally, the California Bearing Ratio (CBR) has been widely used for this purpose. Mechanistic pavement design procedures require elastic modulus and Poisson's ratio as input for all pavement layers, including the sub-grade which is usually treated as an isotropic semi-infinite elastic medium. For this Manual, CBR has been retained as a design tool; however, direct measurement of elastic stiffness values of the sub-grade is recommended whenever feasible. Elastic stiffness values used for the design of the pavement structures presented in this Manual are shown in **Table 4** along with the CBR values used as input values for selecting pavement structures from the catalogue.

A minimum CBR of 5% is recommended for pavements that have to support traffic volumes corresponding to Traffic Classes T 2 through T 5. If the sub-grade (cut or fill) does not meet this minimum CBR requirement, at least 0.3m of unsuitable sub-grade soil shall be replaced or stabilised to ensure that the selected minimum CBR value is obtained under due consideration of applicable moisture conditions and probability of meeting the design input value. For road pavements designed for large volumes of traffic (Traffic Classes T 4 and T 5), a minimum sub-grade strength corresponding to CBR of 12% is recommended. For pavement design purposes, the use of average CBR or sub-grade modulus test results is not recommended; it would signify that there is only a 50% probability that the design input value is met.

Table 4: Classes of Sub-Grade Strength (based on CBR) used as Input in the Pavement Catalogue of this Manual

Sub-Grade Category	**CBR (%)**	**Elastic Modulus (MPa)**	
		Range	**Design Input Value**
SG 1	5 to 12	50 to 120	60
SG 2	12.1 to 20	80 to 140	120
SG 3	20.1 to 30.0	100 to 160	140
SG 4	> 30.0	120 to 180	180

The correlation between sub-grade stiffness and CBR values shown in **Table 4** is based on the following criteria;

- For cohesive soils, a relationship similar to that shown in *TRRL LR 1132: "The Structural Design of Bituminous Roads"* is used.
- For primarily granular materials, information contained in the 1993 edition of the *AASHTO Pavement Design Manual* and in Appendices CC and DD of *Mechanistic-Empirical Design of New & Rehabilitated Pavement Structures ("AASHTO 2002")* is used as primary guideline.

2.4 Properties of Paving Materials

For the purpose of this Manual, paving materials are classified into several categories in accordance with their intended function within the pavement structure. The categories include (from top of the pavement downwards);

- Bituminous wearing and binder courses.
- Bituminous road base.
- Unbound granular road base.
- Cemented or otherwise stabilised road base.
- Unbound granular sub-base.

When shown in project drawings and specifications, recycled asphalt pavement (RAP) shall be used instead of unbound granular road base, or up to 30% of RAP shall be included in bituminous road base. Use of in-place recycled materials, such as CIPR and HIPR, is considered in Section 6 (Rehabilitation of Flexible Pavements) of this Manual. Descriptions of all paving materials used in this Manual are contained in the new PWD Standard Specifications for Road Works[2] and are summarised in Figure 6 of this Manual.

2.5 Bituminous Wearing and Binder Courses

Specifications for bituminous mixtures are contained in the PWD Standard Specifications for Road Works[2]. For the purpose of pavement design, the elastic modulus and Poisson's ratio are the two most important properties of bituminous mixtures.

Elastic modulus of bituminous mixtures is primarily a function of its composition and density, and of the temperature and loading time to which a bituminous mixture is exposed in a pavement. The effect of temperature on elastic modulus and on the Poisson's ratio is pronounced. Within the range of temperatures that can occur in road pavements in Malaysia, elastic modulus values will vary from a few hundred MPa at high pavement temperatures to about 3000 MPa at the low end of pavement temperatures. Over the same temperature range, the Poisson's ratio varies from about 0.35 to 0.45. For the design of pavement structures presented in this Manual, the following average pavement temperatures are adopted;

- Bituminous Wearing and Binder Courses: 35°C
- Bituminous Road Base: 25°C

The design used to develop the catalogue of pavement structures shown in this Manual is based on default values (**Table 5a and 5b**). If mechanistic design is carried out in lieu of adopting one of the pavement structures offered in this Manual, material input parameters similar to those shown below or developed on the basis of mechanistic laboratory tests (elastic modulus) shall be used. The use of design input values that differ by more than 50% from the design values shown below is discouraged.

Table 5a: Elastic Properties of Unmodified Bituminous Mixtures

Bituminous Mixture based on PEN 50/70 Bitumen	**Elastic Modulus (MPa)**		**Poisson's Ratio**	
	25°C	**35°C**	**25°C**	**35°C**
▪ Wearing Course AC 10 and AC 14	----	1500	0.35	0.40
▪ Wearing Course SMA 14 and SMA 20	----	1500	0.35	0.40
▪ Binder Course AC 28	2500	2000	0.35	0.40
▪ Road Base AC 28	2500	---	0.35	---

Table 5b: Elastic Properties of Polymer Modified Bituminous Mixtures

Bituminous Mixture based on PMB	**Elastic Modulus (MPa)**		**Poisson's Ratio**	
	25°C	**35°C**	**25°C**	**35°C**
▪ Wearing Course AC 10 and AC 14	----	1800	0.35	0.40
▪ Wearing Course SMA 14 and SMA 20	----	1800	0.35	0.40
▪ Binder Course AC 28	3200	2500	0.35	0.40
▪ Road Base AC 28	3200	---	0.35	---

Notes to Tables 5a and 5b:

1. The elastic modulus values shown above are based on the bituminous binders as shown in the tables, on average mixture air voids of 5.0%, and on a loading time of 0.1 second (corresponding to a traffic speed of about 60 km/hour at a depth of 10 cm below pavement surface).
2. If PEN 70/100 bitumen is used instead of PEN 50/70, reduce the elastic stiffness values shown in Table 5a by 20%.
3. When polymer modified asphalt is specified, use type and grade of PMB in accordance with PWD standard or project specifications.

2.6 Bituminous Road Base

For the purpose of flexible pavement design, bituminous road base shall be treated similarly to bituminous binder and wearing courses, except that a lower average temperature is used for this layer. The bottom of the bituminous road base is subject to fatigue-type repeated tensile loading, the effect of which is evaluated in traditional and advanced pavement design.

2.7 Crushed Aggregate and Wet Mix Road Base

Unbound granular materials used for road base consist of crushed rock or gravel with a grading that imparts on the mixture a mechanically stable course that is capable of distributing effectively traffic loads transmitted by overlaying bituminous courses. The performance of well graded granular materials is largely governed by their shear strength, stiffness and by material break-down that may occur during construction and as a consequence of heavy traffic. The presence of excessive fine material and moisture has a detrimental influence on stiffness and stress distribution capacity of unbound granular courses. Adequate shear strength and drainage is usually obtained when the percentage of fine material (≤ 0.075 mm) does not exceed 10%. Temperature and loading time have no significant effect on modulus, strength and durability of granular base materials. PWD Standard Specifications for Road Works[2] include two types of granular base material; which is Crushed Aggregate Road Base and Wet-Mix Road Base. Both materials show similar composition, but construction practices are different. The minimum CBR requirement for Crushed Aggregate Road Base and for Wet-Mix Road Base is 80% corresponding to an elastic modulus of about 350 ± 100 MPa.

2.8 Stabilised Road Base

The objective of stabilisation is treatment of a road paving material to correct a known deficiency or to improve its overall performance and thus enhance its ability to perform its function in the pavement. Base materials can be stabilised in-situ or mixed with stabilisers in a plant and laid by a paver or other approved construction equipment. Plant mixed stabilised material tends to be more uniform in composition and strength, and should be preferred. If in-place stabilisation is used, a cold recycler with appropriate mixing chamber should be used. PWD Standard Specifications for Road Works[2] include the following types of stabilised road base;

- Aggregates stabilised primarily with cement and other hydraulic binders (STB 1).
- Aggregates stabilised primarily with bituminous emulsion (STB 2) or a combination of emulsion and cementitious material.

Materials stabilised with cement exhibit higher stiffness and strength, but are more prone to cracking. Materials stabilised primarily with bituminous emulsion show usually lower structural stiffness but are more strain tolerant. Both of these stabilising agents can be combined to yield a paving mixture with desired performance properties. For the design of pavement structures included in the catalogue of this guide, the following elastic modulus and Poisson's ratio values were assumed;

- STB 1: Stabilised base with 3% to 5% Portland cement where E = 1800 MPa; ν = 0.40.
- STB 2: Stabilised base with bituminous emulsion or foamed bitumen and a maximum of 2% Portland cement where E = 1200 MPa; ν = 0.35.

2.9 Temperature

The development of this Manual is based on pavement temperatures that are representative of average climatic conditions in Malaysia as follows;

- Mean Annual Air Temperature: 28°C
- Maximum Air Temperature: 45°C
- Maximum Average Air Temperature during the hottest 7-Day Period (over the Pavement Design Life): 38°C

2.10 Design Period and Reliability

For Traffic Category T 3 through T 5, a design life of 20 years is recommended. For low volume roads and other rural road pavements, a design life of 10 years may be adequate. The above design life and a probability of 85% were used as basis for designing the pavement structures presented in this Manual.

3.0 CATALOGUE OF PAVEMENT STRUCTURES

A catalogue from which pavement structures can be selected for a range of sub-grade support conditions and traffic volumes is presented in Figures 8A, 8B, 8C, 8D and 8E of this Manual. As an example, Figure 8C of this Manual is shown (layer thickness is in cm). These pavement cross sections have been designed for roads and highways that are typical for conditions in Malaysia. For rural and other low volume roads, either cross sections from this catalogue (Traffic Category: < 1 million ESALs) or pavement structures provided in Table 7 of Section 4.1 of this manual can be used. For pavements with unusually severe loading conditions, such as container terminals or other areas where pavements are exposed to high loads and long loading times, the use of a mechanistic design procedure and of special high-performance paving materials is recommended. Pavement materials used in this catalogue are shown in Figure 6 of this Manual and included in the new PWD Standard Specification for Road Works[2].

3.1 Mechanistic Design using Elastic Layer Programs

For the design of pavement structures shown in the catalogue of this Manual, one or more of the following programs were used as design tools:

- *Asphalt Institute SW-1 (based on Manuals MS-1; MS-11; MS-17; MS-23)*
- *Pavement Design: A Guide to the Structural Design of Road Pavements, STANDARDS AUSTRALIA and AUSTROADS, 2004,* in conjunction with *CIRCLY Version 5.0*
- *SHELL SPDM Version 3.0*
- *Pavement Design and Analysis by Yang H. Huang, Second Edition, 2003* in conjunction with *KENLAYER*

4.0 CONCLUDING REMARKS

The newly revised pavement design manual of PWD entitled Design of Flexible Pavement Structures shall replace the current PWD Manual on Pavement Design ie. Arahan Teknik (Jalan) 5/85[1]. The new Manual provides PWD and consultants engaged in pavement engineering projects in Malaysia with a uniform process of designing pavements for all classes of traffic.

The Manual is based on proven, validated pavement design technologies; it builds on past PWD practice and experience and on design methodologies that have been successfully used in other countries over the last twenty years. The design approach recommended in the Manual combines improved design development data and mechanistic methods of analysis into a single tool that is presented in the form of a catalogue of pre-designed pavement structures. In the case of special project conditions or requirements, mechanistic elastic multi-layer design can be carried out using project specific input parameters in conjunction with one of the software programs recommended in the Manual.

5.0 REFERENCES

1. *PUBLIC WORKS DEPARTMENT, MALAYSIA. (1985). Manual On Pavement Design, Arahan Teknik (Jalan) 5/85. Kuala Lumpur,Malaysia.*
2. *PUBLIC WORKS DEPARTMENT, MALAYSIA. (2008). Standard Specifications for Road Works , JKR/SPJ/2008. Kuala Lumpur,Malaysi*

Pavement Type	**Sub-Grade Category**			
	SG 1: CBR 5 to 12	**SG 2: CBR 12.1 to 20**	**SG 3: CBR 20.1 to 30**	**SG 4: CBR > 30**
Conventional Flexible: Granular Base	BSC: 5 BC: 13 CAB: 20 GSB: 20	BSC: 5 BC: 13 CAB: 20 GSB: 20	BSC: 5 BC: 13 CAB: 20 GSB: 15	BSC: 5 BC: 13 CAB: 20 GSB: 10
Deep Strength: Stabilised Base	BSC: 5 BC: 10 STB 1: 15 GSB: 20	BSC: 5 BC: 10 STB 1: 15 GSB: 15	BSC: 5 BC: 10 STB 1: 10 GSB: 15	BSC: 5 BC: 10 STB 1: 10 GSB: 10
Full Depth: Asphalt Concrete Base	BSC: 5 BC/BB: 16 GSB: 20	BSC: 5 BC/BB: 15 GSB: 15	BSC: 5 BC/BB: 13 GSB: 15	BSC: 5 BC/BB: 13 GSB: 10

Figure 8C: Pavement Structures for Traffic Category, T 3: 2.0 to 10.0 million ESALs (80kN)