Manual For The Structural Design of Flexible Pavement

ISBN 978-967-5957-23-9

Jabatan Kerja Raya
Cawangan Kejuruteraan Jalan & Geoteknik

ATJ 5/85 (Pindaan 2013)
JKR 21300-0041-13

KERAJAAN MALAYSIA

MANUAL FOR THE STRUCTURAL DESIGN OF FLEXIBLE PAVEMENT

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Addendum ATJ 5/85 (Pindaan 2013) : Manual for the Structural Design of Flexible Pavement (Surat Arahan KPKR Bil 28/2017 bertarikh 28hb November 2017)

ADDENDUM No.1

Published on 28th of March 2017

The purpose of this addendum is to incorporate new data acquired from the ***Axle Load Study (Bridges) on Federal and Major State Routes in Peninsula Malaysia*** commissioned by JKR and undertaken by Perunding Zaaba (2016).
Mainly the data presented in ***Technical Note 18: Recommendations of Maximum Axle Loading and Vehicle Dimensions for Design of Future Roads and Highways*** with regards to the Classes of Commercial Vehicles and Loading Equivalence Factor (LEF), is taken into consideration for this addendum. The maximum Gross Vehicle Weight has been increased from 44 tonne (as allowed in Weight Restriction Order 2003) to 50 tonne.

This addendum shall be made part of the "*ArahanTeknik Jalan 5/85 (Pindaan 2013): Manual for the Structural Design of Flexible Pavement*"

Amendment 1.

Section 2.2 Determination of Design Traffic (paragraph 6, page 8) shall be read as follows:

Amendment 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 lorries and axle loads. Information from the Axle Load Study (Bridges) on Federal and Major State Routes in Peninsula Malaysia (2016) has been used as a basis for calculating commercial vehicle load factors for traffic classes (**Table 2.1**). In addition, the Axle Load Study (2016) has recommended an increase in the maximum Gross Vehicle Weight from 44 tonne (as allowed in Weight Restriction Order 2003) to 50 tonne.

Amendment 2.

Section 2.2 Determination of Design Traffic (Table 2.1, page 8) shall be read as follows:

Amendment 2. **TABLE 2.1: Axle Configuration and Load Equivalence Factors (LEF)**

Vehicle		Load Equivalence Factor (LEF)
Class Designation	**Class**	
Cars and Taxis	C	0
Rigid Vehicle (1+1) incl. Buses (2 Axle)	CV1	3.9
Rigid Vehicle (1+2) incl. Buses (3 Axle)	CV2	2.8
Rigid Vehicle (2+2) (4 Axle)	CV3	2.6
Articulated Vehicle (1+1+1) (3 Axle)	CV4	7.1
Articulated Vehicle (1+1+2) (4 Axle)	CV5	6.1
Articulated Vehicle (1+1+3) (5 Axle)	CV6	4.7
Articulated Vehicle (1+2+2) (5 Axle)	CV7	4.2
Articulated Vehicle (1+2+3) (6 Axle)	CV8	3.5
Articulated Vehicle (1+2+4) (7 Axle)	CV9	3.6
Motorcycles	MC	0

Amendment 3.

Section 2.3 Design Procedure Recommended in This Manual (Clause 1.b., page 9) shall be deleted and existing 1.c. to be renumbered as 1.b.

2.3 Design Procedure Recommended in this Manual

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.

Amendment 3. ~~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 2.1**).~~

   c. Average Annual **Traffic Growth Factor (r)** for CV.

Amendment 4.

Section 2.3 Design Procedure Recommended in This Manual (Note., page 9) shall be read as follows:

Amendment 4. Note: *The design period chosen shall be checked against Maximum Hourly One Way Traffic Flow capacity (ATJ 8/86 Pindaan 2015 A Guide On Geometric Design Of Roads) If the traffic capacity is exceeded before the design period, the designer may reduce the design period used in the design accordingly. Alternatively, the design period may be allowed to exceed the time taken to reach traffic capacity. In this regard, a proper pavement evaluation works shall be carried out if future road upgrading works is deemed necessary.*

Amendment 5.

Section 2.3 Design Procedure Recommended in This Manual (Clause 4., page 10) shall be read as follows, whereby Equation 1 is replaced by Equation 2 in its entirety:

Amendment 5. 4. Site specific distribution of traffic by vehicle type is required to determine the ESAL.The calculation of the **Design Traffic (Number of ESALs) for the Design Lane and Base Year Y_1 (First Year of Design Period)** is as follows: -

$$\mathbf{ESAL_{Y1} = [ADT_{vc1} x\ LEF_1 + ADT_{vc2}\ x\ LEF_2 + \ldots + ADT_{vc9}\ x\ LEF_9]\ x\ 365\ x\ L\ x\ T} \quad \ldots(1)$$

where;

$ESAL_{Y1}$ = Number of ESALs for the Base Year (Design Lane)

ADT_{VC2}, etc = Average Daily Number of Vehicles in each Vehicle Class

LEF_2, etc = Load Equivalence Factors of applicable vehicle class

L = Lane Distribution Factor (refer to **Table 2.2**)

T = Terrain Factor (refer to **Table 2.3**)

Amendment 6.

Section 2.5.1 Bituminous Wearing and Binder Courses (Table 2.7, page 15) shall be read as follows:

TABLE 2.7: Elastic Properties of Unmodified Bituminous Mixtures

Amendment 6.

Bituminous Mixture based on **PEN 60/70 Bitumen**	Elastic Modulus (MPa)		Poisson's Ratio	
	25°C	35°C	25°C	35°C
▪ Wearing Course AC 10 and AC 14	----	1440	0.35	0.40
▪ Wearing Course SMA 14 and SMA 20	----	1440	0.35	0.40
▪ Binder Course AC 28	2400	1920	0.35	0.40
▪ Road Base AC 28	2400	---	0.35	---

Amendment 7.

Section 2.5.1 Bituminous Wearing and Binder Courses (Notes: 2., page 16) shall be deleted and existing 3. to be renumbered as 2.

Notes :

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).*

Amendment 7. ~~2. *If PEN 60/70 bitumen is used instead of PEN 80/100, increase the elastic stiffness values shown in **Table 2.7** by 20%.*~~

3. *When polymer modified asphalt is specified, use type and grade of PMB in accordance with JKR Standard Specification for* Road Works JKR/SPJ/2008 – Section 4.

Amendment 8.

Section 5 Worked Examples (page 34 - 38) shall be deleted in its entirety and replaced as follows, with pages renumbered from 34 - 36 accordingly:

5.1 Full-Depth Asphalt Pavement

Design a road pavement for a 4-lane freeway (concession toll-road) with an average daily traffic of 7286 vehicles, of which 20% are commercial vehicles with an un-laden weight > 1.5 tons.

Step 1: Development of Design Input

ADT based on HPU survey (from 06:00 to 22:00 hours);

- o CV 1 = 624 x 1.2 = 749 vehicles per 24-hour period
- o CV 2 = 102 x 1.2 = 122 vehicles per 24-hour period
- o CV 3 = 456 x 1.2 = 547 vehicles per 24-hour period
- o CV 4 = 86 x 1.2 = 103 vehicles per 24-hour period
- o CV 5 = 75 x 1.2 = 90 vehicles per 24-hour period
- o CV 6 = 63 x 1.2 = 76 vehicles per 24-hour period
- o CV 7 = 47 x 1.2 = 56 vehicles per 24-hour period
- o CV 8 = 32 x 1.2 = 38 vehicles per 24-hour period
- o CV 9 = 13 x 1.2 = 16 vehicles per 24-hour period

Lane Distribution Factor, L = 0.9 (two lanes in one direction) (Refer to Table 2.2)

Terrain Factor, T = 1.0 (flat) (Refer to Table 2.3)

Design Life, n = 20 years

Assumed Annual Traffic Growth Rate, r = 4.5%

Step 2 : Determine Design Traffic (Traffic Category)

ESALY1 (Base Year) = [(ADTCV1 x LEF1) + (ADTCV2 x LEF2) + (ADTCV3 x LEF3) + (ADTCV4 x LEF4) + (ADTCV5 x LEF5) + (ADTCV6 x LEF6) + (ADTCV7 x LEF7) + (ADTCV8 x LEF8) + (ADTCV9 x LEF9)] x 365 x L x T

= [(749 x 3.9) + (122 x 2.8) + (547 x 2.6) + (103 x 7.1) + (90 x 6.1) + (76 x 4.7) + (56 x 4.2) + (38 x 3.5) + (16 x 3.6)] x 365 x 0.9 x 1.0

= 2.217 million

Design Traffic over 20 Years;

ESALDES = ESALY1 x [(1 + r)n – 1)]/r

= 2.217 million x 31.37

= 69.5 million

= Traffic Category T 5 (Refer to Table 2.5)

Step 3: Determine Sub-Grade Strength (Sub-Grade Category)

Results from Sub-Grade testing: -

Mean Modulus (H-FWD) = 165 MPa

Standard Deviation (H-FWD) = 28 MPa

Reliability 95% (Normal Deviate = 1.645)

Characteristic Sub-Grade Modulus value used for design:

= Mean – (Normal Deviate x Standard Deviation)

= 165 MPa – (1.645 x 28 MPa)

= 165 MPa – 46 MPa

= 119 MPa

= Sub-Grade Category SG 3 (Refer to Table 2.5)

Note: Use design input value from Table 2.6 equal to:

(119 + 165)/2 ~ 140)

Step 4: Select one of the pavement structures from Figure 3.5 (T 5, SG 3)

- **OPTION 1: Conventional flexible pavement with unmodified bitumen and granular base:**
  - Bituminous Surface Course (AC 10 or AC 14): 50 mm
  - Bituminous Binder Course/Road Base (AC 28): 190 mm

- Crushed Aggregate Road Base: 200 mm
- Granular Sub-Base: 150 mm

▪ **OPTION 2: Full-Depth Asphalt Pavement with unmodified bitumen:**

  - Bituminous Surface Course (AC 10 or AC 14): 50 mm
  - Bituminous Binder Course and Road Base: 200 mm
    - Bituminous Binder Course (AC 28): 60 mm
    - Bituminous Road Base (AC 28): 140 mm
  - Granular Sub-Base: 150 mm

Note: If asphalt binder and base course mixtures are based on the same type of binder and aggregate gradation, the thickness of binder and base course are interchangeable, that is, instead of 6 cm binder course and 14 cm base course, 10 cm binder course and 10 cm base course can be selected.

▪ **OPTION 3: Use 40 mm polymer modified SMA 14 instead of 50 mm unmodified AC 10 or AC 14**

FOREWORD

The purpose of this Arahan Teknik (Jalan) 5/85 (Pindaan 2013), hereinafter called **ATJ 5/85 (Pindaan 2013) : Manual for the Structural Design of Flexible Pavement**, is to provide JKR and consultants engaged in pavement engineering projects in Malaysia with a uniform process of designing pavements for all classes of traffic. This Manual is based on proven, validated pavement design technologies; it builds on past JKR practice and experience and on design methodologies that have been successfully used in other countries. The design approach recommended in this Manual combines improved design development data and mechanistic methods of analysis into a single tool that is presented in the form of catalogue of predesigned pavement structures.

This Manual will supersede the existing JKR pavement design manual (Arahan Teknik Jalan 5/85) which is based on Asphalt Institute and AASHTO design procedures which have undergone several revisions to date. This Manual is also a revised version of the JKR pavement design manual (JKR 20601-LK-0156-KP-05) which was prepared under Cawangan Pakar dan Kejuruteraan Awam in 2006.

The preparation of this Manual was carried out through many discussions held by the committee members who are experts in their respective fields. Feedbacks and comments received were carefully considered and incorporated into the Manual wherever appropriate. This Manual had also been presented and approved in the *Mesyuarat Jawatankuasa Pemandu Pengurusan* Bil. 2/2013 on 15th January 2013.

This Manual will be reviewed and updated from time to time to incorporate the latest development in pavement technologies. In this respect, any comments and feedback regarding this Manual should be forwarded to Unit Standard & Spesifikasi, Cawangan Kejuruteraan Jalan & Geoteknik.

Published by: -

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ACKNOWLEDGEMENT

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MANUAL FOR THE STRUCTURAL DESIGN OF FLEXIBLE PAVEMENT

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SECTION 1: INTRODUCTION AND OVERVIEW

1.0 OVERVIEW OF THIS MANUAL

1.1 Purpose

The purpose of this Manual on design of flexible pavement structures is to provide JKR and consultants engaged in pavement engineering projects in Malaysia with a uniform process of designing pavements for all classes of traffic. This Manual is based on proven, validated pavement design technologies; it builds on past JKR 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 this 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 this Manual.

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.

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. This Manual does not contain information related to the structural design of new rigid pavements.

1.2 Outline of this Manual

This Manual is divided into the following sections: -

- **Section 2** explains the design process and information needed for designing a pavement in accordance with this Manual.
- **Section 3** describes the flexible pavement design procedure used in this Manual and presents a catalogue of pre-designed pavement structures. The primary selection of a pavement structure is based on design traffic volume and sub-grade strength. For the same set of input parameters, alternative pavement sections are provided in which case regional experience with specific types of paving materials and cost of materials shall be considered in the selection process.
- **Section 4** provides information about pavement design for low volume roads and for highly stressed pavements.
- **Section 5** presents worked examples using information contained in this Manual.

1.3 Definitions of Pavement Layers

Pavements are usually composed of layers of different materials; layering of a pavement has a significant effect on its performance. Composition, density and thickness of paving materials (bituminous materials, stabilised granular materials, unbound granular road base and sub-base) shall be selected so that they perform as an integral structure and meet intended performance requirements.

Key components of a typical flexible pavement are shown in **Figures 1.1, 1.2** and **1.3**, and are for the purpose of this Manual defined as follows: -

- **Sub-Grade**

  Sub-grade is a soil or rock formation that forms the foundation of a pavement structure; it consists of a prepared cut or compacted fill. The pavement structure shall be designed so that stresses and strains due to traffic loads on the sub-grade remain within tolerable limits. These limits are a function of the elastic stiffness and bearing capacity of the sub-grade and of the traffic volume that a pavement is designed for.

  When required and specified, weak sub-grade materials shall be replaced with selected materials or stabilised up to depth of at least 300 mm below sub-grade level to provide a suitable platform for construction traffic and a sound foundation for the pavement. Sub-grade improvement shall not be considered as a separate layer in mechanistic pavement design and is not shown in the catalogue of pavement structures.

- **Sub-Base**

Sub-base shall consist of a layer of specified material composition, stiffness and thickness placed directly on the sub-grade. Sub-base shall be considered as lower road base that supports the upper road base and that aids in distributing traffic induced stresses. Because stress levels are lower in the sub-base course than in the road base, sub-base materials are usually of lower quality and stiffness than materials used as road base.

- **Road Base**

Road base is the main structural layer of a pavement. In flexible pavements, it shall consist of bituminous mixtures, or a granular layer stabilised with cement, emulsion, or similar materials, or mechanically stabilised but otherwise unbound crushed aggregate road base or wet-mix road base. Its key function is to distribute traffic loads so that sub-base and sub-grade are not subjected to excessive stresses and strains.

- **Bituminous Binder Course**

Bituminous binder course is usually considered part of the surface layers of a pavement. A binder course shall have good resistance to shear-induced distress, because shear stress is highest at a depth of about 0.9 times the radius of the contact area of a wheel load, which corresponds in the case of most commercial vehicles to a depth of about 8 to 12 cm below the pavement surface.

- **Bituminous Wearing Course**

Bituminous wearing course shall meet both structural (resistance to stresses and strains imposed by traffic loads) and functional performance requirements; the latter includes adequate durability (resistance to the disintegrating effects of climate), good frictional characteristics and smoothness.

TYPICAL FLEXIBLE PAVEMENT STRUCTURES

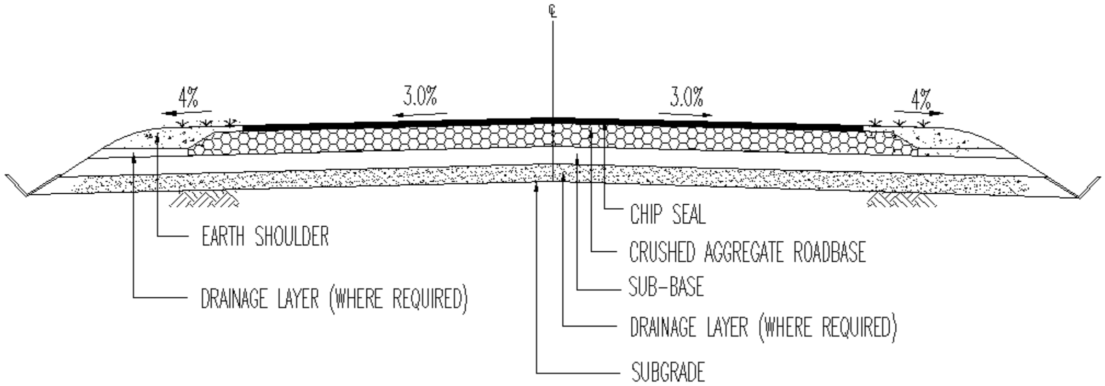

FIGURE 1.1: Single Carriageway – Minor (Low-Volume) Road

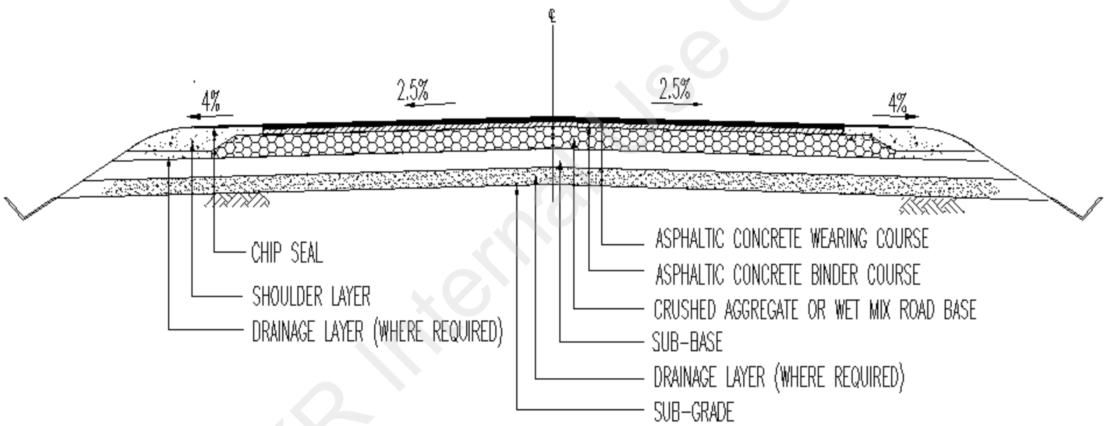

FIGURE 1.2: Single Carriageway – Major Road

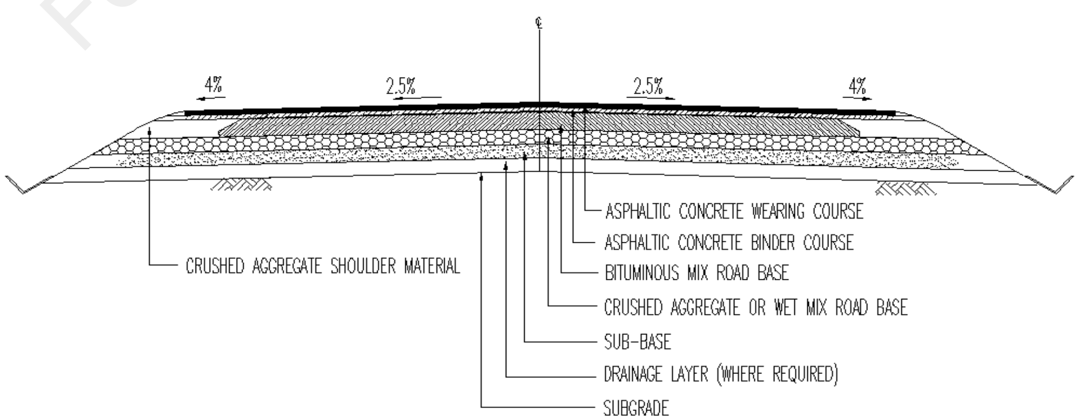

FIGURE 1.3: Dual Carriageway – Major Road

SECTION 2: INFORMATION NEEDED FOR PAVEMENT DESIGN

2.0 INFORMATION NEEDED AS INPUT FOR PAVEMENT DESIGN

The following key information is needed for design of flexible pavements in accordance with this Manual. Such information shall be collected and diligently evaluated before finalising the pavement structure.

- Types and volumes of commercial vehicles for which the pavement structure is designed.
- Design life.
- Sub-grade type and strength.
- Types and properties of paving materials used.
- Environment to which the pavement structure will be exposed.

2.1 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 (**Figure 2.1**): -

- 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.

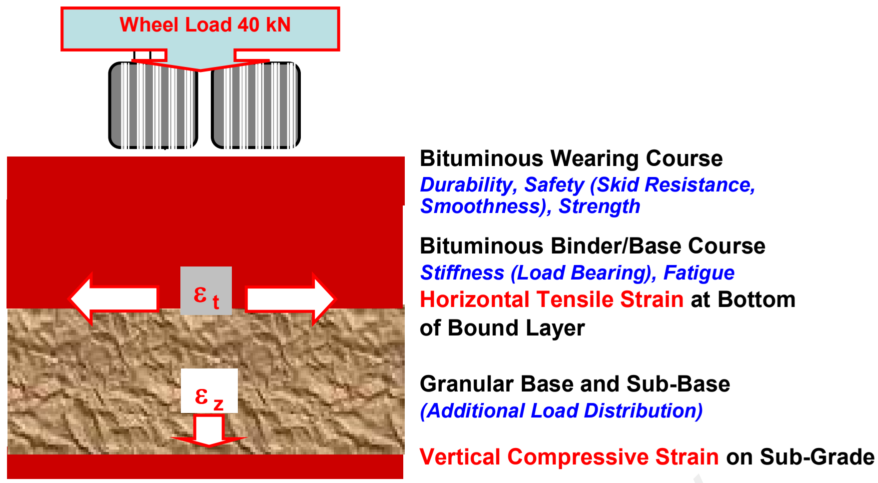

FIGURE 2.1: Components of a Typical Flexible Pavement Structure

Because of many variables and interactions that influence performance of a pavement, a systematic approach to pavement design is recommended. It allows visualising the relationship between input variables, analysis methods, and the decision process which comprise pavement design. Key elements of a systematic pavement design procedure are shown in **Figure 2.2**.

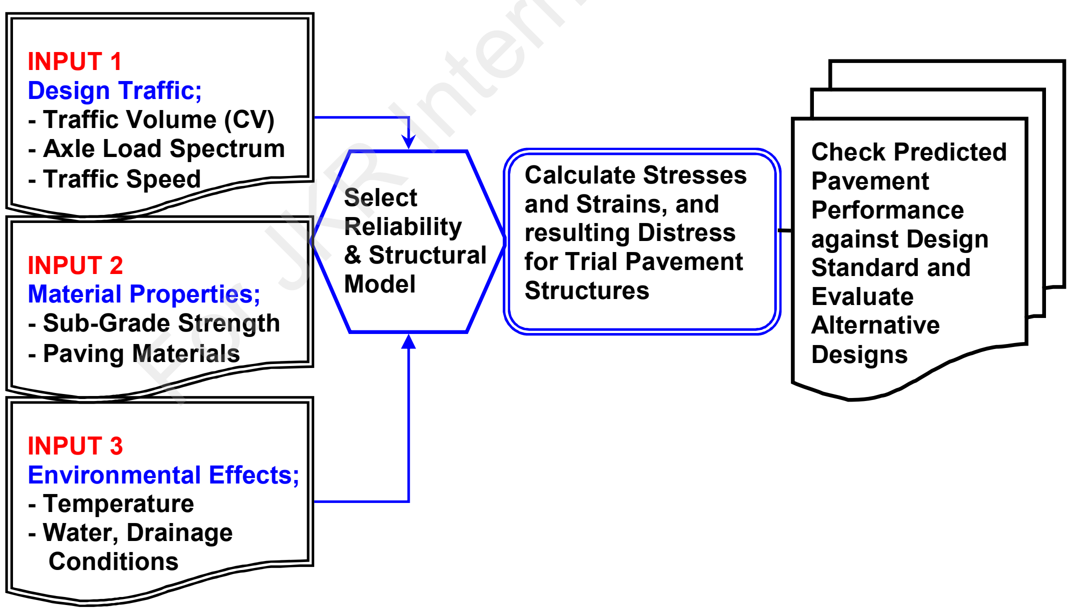

FIGURE 2.2: Generalised Outline of Mechanistic Pavement Design Procedure

2.2 Determination of Design Traffic

Traffic data is a key input parameter for structural design of pavements. This information is needed to determine the loads that must be supported over the selected design life of the pavement. Two elements of traffic load which are of particular importance are: -

- Standard axle or wheel load.
- Traffic spectrum and traffic volume expressed as number of standard axle loads assumed during the design life of the pavement.

The Equivalent Standard Axle Load (ESAL) in Malaysia 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. 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.
- 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 2.1**.

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 lorries 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 2.1**).

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

TABLE 2.1: Axle Configuration and Load Equivalence Factors (LEF) based on Traffic Categories used by HPU

Vehicle		Load Equivalence Factor (LEF)
HPU Class Designation	**Class**	
Cars and Taxis	C	0
Small Lorries and Vans (2 Axles)	CV1	0.1
Large Lorries (2 to 4 Axles)	CV2	4.0
Articulated Lorries (3 or more Axles)	CV3	4.4
Buses (2 or 3 Axles)	CV4	1.8
Motorcycles	MC	0
Commercial Traffic (Mixed)	CV%	3.7

2.3 Design Procedure Recommended in this Manual

The procedure for calculating the **Traffic Category** to be used as design input (number of 80 kN ESALs over Design Period, see **Table 2.5**), 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 2.1**).

   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 based on economic and social consideration. Design period of 10 years is recommended for low volume roads and other rural roads. A minimum design period of 20 years is recommended for roads having medium to high volume traffic.

   Note: *The design period chosen shall be checked against Maximum Hourly One Way Traffic Flow capacity (refer to A Guide on Geometric Design of Roads REAM GL2/2002). If the traffic capacity is exceeded before the design period, the designer may reduce the design period used in the design accordingly. Alternatively, the design period may be allowed to exceed the time taken to reach traffic capacity. In this regard, a proper pavement evaluation works shall be carried out if future road upgrading works is deemed necessary.*

4. Calculate the **Design Traffic (Number of ESALs) for the Design Lane and Base Year Y_1 (First Year of Design Period)** using the following formula: -

$$\mathbf{ESAL_{Y1} = ADT \times 365 \times P_{CV} \times 3.7 \times L \times T} \quad \ldots (1)$$

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 ton

L = Lane Distribution Factor (refer to **Table 2.2**)

T = Terrain Factor (refer to **Table 2.3**)

If site specific distribution of traffic by vehicle type is available, *Equation (1)* shall be refined as follows;

$$\mathbf{ESAL_{Y1} = [ADT_{vc1} \times LEF_1 + ADT_{vc2} \times LEF_2 + \ldots + ADT_{vc4} \times LEF_4] \times 365 \times L \times T} \quad \ldots (2)$$

where;

ADT_{VC2}, etc = Average Daily Number of Vehicles in each Vehicle Class

LEF_2, etc = Load Equivalence Factors 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 2.2** and **2.3** below.

TABLE 2.2: 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 2.3** below.

TABLE 2.3: 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;

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

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 = Average 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 2.4** below.

$$\textbf{Design Traffic } ESAL_{DES} = ESAL_{Y1} \times TGF \quad \dots (3a)$$

TABLE 2.4: Total Growth Factors (TGF)

Design Period (Years)	Annual Growth Rate (%)					
	2	3	4	5	6	7
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, the predicted traffic expressed as number of ESALs over the design period is classified into several traffic categories (refer **Table 2.5**). Traffic Category T 1 represents low traffic volume; Traffic Category T2 for traffic between 1.0 and 2.0 million ESAL and so on; T5 represent design traffic of more than 30 million ESAL.

Road pavements for low traffic volume are discussed in more detail in Sub-Section 4.1 of this Manual.

TABLE 2.5: 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

2.4 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 2.6 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 1 through T 5. If the sub-grade (cut or fill) does not meet this minimum CBR requirement, at least 300 mm 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 2.6: 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 2.6** above 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.

2.5 Properties of Paving Materials

Pavement design in accordance with the procedure outlined in this Manual permits the use of a range of paving materials, provided that such materials meet the requirements of JKR Standard Specifications for Road Works, JKR/SPJ/2008 – Section 4. The choice of materials shall be based on considerations of regional experience and availability of materials, and on costs.

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.

Descriptions of all paving materials used in this Manual are contained in the JKR Standard Specifications for Road Works JKR/SPJ/2008 – Section 4 and are summarised in **Figure 2.3** of this Manual.

2.5.1 Bituminous Wearing and Binder Courses

Specifications for bituminous mixtures are contained in the JKR Standard Specifications for Road Works JKR/SPJ/2008 – Section 4. 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 2.7** and **2.8** below). 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 2.7: Elastic Properties of Unmodified Bituminous Mixtures

Bituminous Mixture based on **PEN 80/100 Bitumen**	Elastic Modulus (MPa)		Poisson's Ratio	
	25°C	35°C	25°C	35°C
▪ Wearing Course AC 10 and AC 14	----	1200	0.35	0.40
▪ Wearing Course SMA 14 and SMA 20	----	1200	0.35	0.40
▪ Binder Course AC 28	2000	1600	0.35	0.40
▪ Road Base AC 28	2000	---	0.35	---

TABLE 2.8: 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	----	1400	0.35	0.40
▪ Wearing Course SMA 14 and SMA 20	----	1400	0.35	0.40
▪ Binder Course AC 28	2500	2000	0.35	0.40
▪ Road Base AC 28	2500	---	0.35	---

Notes :

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 60/70 bitumen is used instead of PEN 80/100, increase the elastic stiffness values shown in **Table 2.7** by 20%.*
3. *When polymer modified asphalt is specified, use type and grade of PMB in accordance with JKR Standard Specification for* Road Works JKR/SPJ/2008 – Section 4.

2.5.2 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.

2.5.3 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. JKR Standard Specifications for Road Works, JKR/SPJ/2008 – Section 4 include two types of granular base material: -

- Crushed Aggregate Road Base
- Wet-Mix Road Base

Both materials show similar composition, but construction practices are different. The minimum CBR requirement for Crushed Aggregate Road Base and Wet-Mix Road Base is 80% corresponding to an elastic modulus of about 350 ± 100 MPa.

2.5.4 Stabilised Road Base

The objective of stabilisation is to correct a known deficiency of paving materials 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. JKR Standard Specifications for Road Works, JKR/SPJ/2008 – Section 4 include the following types of stabilised road base: -

- Aggregates stabilised primarily with cement or lime (STB 1).
- Aggregates stabilised primarily with a combination of bituminous emulsion/foamed bitumen and cementitious material (STB 2).

Materials stabilised with cement exhibit higher stiffness and strength, but are more prone to cracking. Materials stabilised primarily with bituminous emulsion/foamed bitumen 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. Typical stiffness values for stabilised base using cement, lime, bituminous emulsion and foamed bitumen range from 800 to 3000 MPa, 800 to 1200 MPa, 1200 to 2000 MPa and 1200 to 2000 MPa respectively. For the design of pavement structures included in the catalogue of this manual, the following elastic modulus and Poisson's ratio values were assumed: -

- STB 1: Stabilised base with 3% to 5% Portland cement.

  E = 1800 MPa; v = 0.40

- STB 2: Stabilised base with bituminous emulsion or foamed bitumen and a maximum of 2% Portland cement.

  E = 1200 MPa; v = 0.35

Figure 2.3: Summary of Materials used in Pavement Structures in Malaysia

NEW PAVEMENT DESIGN AND CONSTRUCTION		
DESIGNATION	**DESCRIPTION**	**ABBREVIATION/ SYMBOL**
DRAINAGE LAYER	Primarily functional granular layer with load distribution capability similar to the Sub-Base	DL
SUB-BASE COURSE	Crushed or natural granular material with maximum 10% fines	GSB
ROAD BASE COURSE		
• **Crushed Aggregate**	Crushed granular material with maximum 10% fines	CAB
• **Wet Mix**	Crushed granular material with maximum 10% fines	WMB
• **Bituminous**	Coarse bituminous mix (AC 28)	BB
• **STB 1**	Stabilised base with at least 3% Portland cement.	STB1
• **STB2**	Stabilised base with bituminous emulsion and maximum of 2% Portland cement	STB2
BINDER COURSE		
• **Binder Course**	Coarse bituminous mix (AC 28)	BC
WEARING COURSE		
• **Asphaltic Concrete**	Medium to fine bituminous mix (AC 10 or AC 14).	BSC
• **Polymer Modified Asphalt (PMA)**	Medium to fine bituminous mix (AC 10 or AC 14) incorporated with polymer modified bitumen.	PMA
• **Stone Mastic Asphalt (SMA)**	Stone mastic asphalt (SMA 14 or SMA 20)	SMA
• **Porous Asphalt**	Primarily functional porous asphalt (PA 10 or PA 14)	PA
• **Gap-Graded Asphalt**	Gap Graded Asphalt GPA I or GPA II	FC

THIN SURFACING		
• **Micro surfacing**	Application of modified version of slurry seal consists of a mixture of polymer modified bitumen emulsion, selected mineral aggregate, mineral filler, water and other additives such as cement and latex, properly proportioned, mixed and spread on existing bituminous surfacing.	MS
• **Chip Seal**	Application of binder in the form of an emulsion or bitumen, followed by an application of single size aggregate.	CS

2.6 <u>Environmental Effects</u>

2.6.1 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

2.6.2 Precipitation and other Moisture

The detrimental effect of moisture on pavement performance is an important consideration in wet tropical regions. It affects long-term performance of granular or stabilized base and sub-base, and of the sub-grade. Subsurface water can decrease appreciably strength and modulus of these materials, if they are allowed to become saturated for extended periods of time. Water affects the structural performance of a pavement through premature surface depressions, rutting, pothole formation, and cracking. In the case of bituminous mixtures, stripping and subsequent accelerated aging, ravelling, and pothole formation may occur.

Measures that can be employed to control or reduce moisture induced damage include: -

- Prevent moisture from entering the pavement system.
- Incorporate design features that remove moisture that enters the pavement system. The use of drainage layers is recommended.
- Use paving materials that are insensitive to the effects of moisture.

2.7 Design Period and Reliability

A pavement design process cannot guarantee with certainty that a constructed pavement will perform exactly as intended by the designer. Key reasons for this fact are: -

- Current design methodologies do not model exactly stresses and strains that occur in pavements due to environment and traffic loads.
- Traffic volume and axle load spectra used as design input are approximations.
- Material properties used as design input values are simplifications of complex and variable conditions that occur in sub-grade, crushed aggregate base and asphalt layers.
- A construction process does usually not produce a pavement in complete conformance with design and specifications.

Because of this variability, a concept of reliability based on statistical parameters should be adopted in pavement design. Reliability is an expression of the probability that a pavement constructed with reasonable conformance to design and specifications will support the design traffic for the intended design period without significant distress.

For Traffic Category T 3 through T 5, a design life of 20 years is recommended. For low volume roads and other rural roads (T 1 and T 2), 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.

SECTION 3: DESIGN OF STANDARDISED PAVEMENT STRUCTURES

3.0 DESIGN OF STANDARDISED PAVEMENT STRUCTURES

Pavement structures contained in this Manual are based on the following design philosophy: -

- Experience has shown that pavements will perform satisfactorily and maintenance requirements and life cycle costs will be low if the thickness of the bound (asphalt or stabilised) layer is ≥ 18 cm. For this reason, a minimum of 18 cm of bituminous material is recommended for pavements designed for Traffic Categories T 3 or higher.
- Underneath bituminous pavement courses, a minimum combined thickness of granular road base and sub-base of 30 cm and a minimum thickness of granular road base of 20 cm are used for all Traffic Categories. For full-depth asphalt pavements, a minimum thickness granular sub-base of 10 cm may be used at the discretion of the designer.
- The recommended minimum thickness of pavement layers as a function of Traffic Category and Sub-Grade Strength is shown in **Table 3.1** below.

TABLE 3.1: Conceptual Outline of Pavement Structures used in this Manual

Pavement Structure	Traffic Category (based on million ESALs @ 80 kN)				
	≤ 1	*1 to 2*	*2.1 to 10*	*10.1 to 30*	*> 30*
	T 1	T 2	T 3	T 4	T 5
▪ Combined Thickness of Bituminous Layers	5 cm	10 cm	18 cm	20 cm	24 cm
Crushed Aggregate Road Base + Sub-Base for Sub-Grade CBR of:					
○ 5 to 12	25+15 cm	20+15 cm	20+20 cm	NR	NR
○ 12.1 to 20	20+15 cm	20+15 cm	20+20 cm	20+20 cm	20+20 cm
○ 20.1 to 30	20+10 cm	20+10 cm	20+15 cm	20+15 cm	20+15 cm
○ > 30	20 cm	20+10 cm	20+10 cm	20+10 cm	20+10 cm

3.1 Types of Standardised Pavement Structures

Pavement structures shown in Section 3.3 (Catalogue of Pavement Structures) are divided into the following three groups: -

- Conventional flexible pavement with granular base.
- Deep-strength flexible (composite) pavement with bituminous surface course(s) and a base stabilised with Portland cement, bituminous emulsion, or a combination of both.
- Full-depth asphalt pavement with bituminous base course.

Selection of a particular pavement structure should be based on regional availability and cost of paving materials and on desired reliability. Deep-strength and full-depth asphalt pavements are generally superior to conventional flexible pavement structures with granular base.

3.2 Critical Pavement Strain

Pavement structures shown in this Manual have been designed to ensure the vertical strain on top of subgrade and the horizontal strain at the bottom of the lowest bound pavement course remain within an acceptable range.

3.3 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 the following **Figures 3.1** through **3.6**. 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 4.1** of Section 4.1 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 2.3** and included in the JKR Standard Specifications for Road Works, JKR/SPJ/2008 – Section 4. Layer thickness in **Figures 3.1, 3.2, 3.3, 3.4, 3.5** and **3.6** are shown in mm.

FIGURE 3.1: Pavement Structures for Traffic Category T 1: < 1.0 million ESALs (80 kN)

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: 50 CAB: 250 GSB: 150	BSC: 50 CAB: 200 GSB: 150	BSC: 50 CAB: 200 GSB: 100	BSC: 50 CAB: 100 GSB: 100
Deep Strength: Stabilised Base	BSC: 50 STB 2: 100 GSB: 200	BSC: 50 STB 2: 100 GSB: 150	BSC: 50 STB 2: 100 GSB: 100	BSC: 50 STB 2: 100 GSB: 100
Stabilised Base with Surface Treatment*	Surface Treatment** GSB: 300 or Surface Treatment** STB 2: 250	Surface Treatment** GSB: 300 or Surface Treatment** STB 2: 250	Surface Treatment** GSB: 250 or Surface Treatment** STB 2: 200	Surface Treatment** GSB: 250 or Surface Treatment** STB 2: 200

Notes:

* *Full Depth Asphalt Concrete Pavement is not recommended for this Traffic Category.*

** *Single or Double Layer Chip Seal or Micro-Surfacing.*

FIGURE 3.2: Pavement Structures for Traffic Category T 2: 1.0 to 2.0 million ESALs (80 kN)

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: 140 CAB: 200 GSB: 150	BSC: 140 CAB: 200 GSB: 150	BSC: 120 CAB: 200 GSB: 100	BSC: 100 CAB: 200 GSB: 100
Deep Strength: Stabilised Base	BSC: 120 STB 2: 150 GSB: 200	BSC: 120 STB 2: 150 GSB: 150	BSC: 100 STB 2: 120 GSB: 150	BSC: 100 STB 2: 120 GSB: 150
Full Depth: Asphalt Concrete Base	BSC: 50 BB: 100 GSB: 250	BSC: 50 BB: 100 GSB: 200	BSC: 50 BB: 100 GSB: 150	BSC: 50 BB: 80 GSB: 150

FIGURE 3.3: Pavement Structures for Traffic Category T 3: 2.0 to 10.0 million ESALs (80 kN)

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: 50 BC: 130 CAB: 200 GSB: 200	BSC: 50 BC: 130 CAB: 200 GSB: 200	BSC: 50 BC: 130 CAB: 200 GSB: 150	BSC: 50 BC: 130 CAB: 200 GSB: 100
Deep Strength: Stabilised Base	BSC: 50 BC: 100 STB 1: 150 GSB: 200	BSC: 50 BC: 100 STB 1: 150 GSB: 150	BSC: 50 BC: 100 STB 1: 100 GSB: 150	BSC: 50 BC: 100 STB 1: 100 GSB: 100
Full Depth: Asphalt Concrete Base	BSC: 50 BC/BB: 160 GSB: 200	BSC: 50 BC/BB: 150 GSB: 150	BSC: 50 BC/BB: 130 GSB: 150	BSC: 50 BC/BB: 130 GSB: 100

FIGURE 3.4: Pavement Structures for Traffic Category T 4: 10.0 to 30.0 million ESALs (80 kN)

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	Sub-Grade Improvement is Recommended	BSC: 50 BC/BB: 150 CAB: 200 GSB: 200	BSC: 50 BC/BB: 150 CAB: 200 GSB: 150	BSC: 50 BC/BB: 150 CAB: 200 GSB: 100
Deep Strength: Stabilised Base		BSC: 50 BC/BB: 150 STB1: 120 GSB: 200	BSC: 50 BC/BB: 140 STB1: 100 GSB: 150	BSC: 50 BC/BB: 130 STB1: 100 GSB: 100
Full Depth: Asphalt Concrete Base		BSC: 50 BC/BB: 200 GSB: 200	BSC: 50 BC/BB: 180 GSB: 150	BSC: 50 BC/BB: 150 GSB: 100

FIGURE 3.5: Pavement Structures for Traffic Category T 5: > 30.0 million ESALs (80 kN)

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	Sub-Grade Improvement is Recommended	BSC: 50 BC/BB: 190 CAB: 200 GSB: 200	BSC: 50 BC/BB: 190 CAB: 200 GSB: 150	BSC: 50 BC/BB: 190 CAB: 200 GSB: 100
Deep Strength: Stabilized Base		BSC: 50 BC/BB: 160 STB1: 150 GSB: 200	BSC: 50 BC/BB: 140 STB1: 150 GSB: 150	BSC: 50 BC/BB: 140 STB 1: 150 GSB: 100
Full Depth: Asphalt Concrete Base		BSC: 50 BC/BB: 210 GSB: 200	BSC: 50 BC/BB: 200 GSB: 150	BSC: 50 BC/BB: 180 GSB: 100

FIGURE 3.6: Pavement Structures for Traffic Category T 5: > 30.0 million ESALs (80 kN)

(Use of Polymer Modified Asphalt)

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
Special Purpose Surface Course	Sub-Grade Improvement is Recommended	SMA, PA, FC or PMA: 50 BC/BB : 170 OR PMA : 140 CAB: 200 GSB: 200	SMA, PA, FC or PMA: 50 BC/BB: 160 OR PMA : 130 CAB: 150 GSB: 150	SMA, PA, FC or PMA: 50 BC/BB: 150 OR PMA : 120 CAB: 100 GSB: 100
Deep Strength High-Modulus Base Course		BSC: 50 PMA Base: 250 GSB: 200	BSC: 5 PMA Base: 220 GSB: 15	BSC: 50 PMA Base: 200 GSB: 100

3.4 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*
- *Layer Elastic Theory using RUBICON TOOLBOX Version 2.9.8.*

The use of the above design programs may yield pavement structures with thicker bituminous pavement layers than adopted in the catalogue of this Manual. It is important to understand and accept that no single mechanistic design method yields a pavement structure that is in absolute terms correct. All design methods require a diligent evaluation of input parameters and a sound balance of performance risks and total costs, which should include construction costs, realistically projected maintenance costs and user costs.

SECTION 4: DESIGN OF SPECIAL PAVEMENT STRUCTURES

4.0 DESIGN OF SPECIAL PAVEMENT STRUCTURES

For most pavement design tasks, a pavement structure from the catalogue will offer satisfactory performance at reasonable costs. For projects that require unique solutions, consideration can be given to adopting a more conservative design (if the project is of particular strategic importance), or to accepting a higher level of performance risk. The latter option can be considered for roads with very low traffic volumes.

On the other hand, port facilities or other trafficked areas that are exposed to unusual loading conditions (high stress; long loading times; channelised traffic), may require very strong pavement structures. In such cases, the use of special materials and design procedures is recommended.

4.1 Pavements for Low-Volume Roads

Low volume road pavements can be designed using pavement cross sections shown in the catalogue under Traffic Category T 1 (< 1.0 million ESALs over the design life of the pavement) or using Table 4.1 below. Column 3 (500 to 1000 x 1000 ESALs) is identical to Category T 1. Lower traffic volumes shown in Table 4.1 below offer alternative designs for very low traffic volumes. Pavement structures shown in Table 4.1 include three Sub-Categories of Traffic and three types of material: a bituminous surface course (BSC), a crushed aggregate base course (CAB) and granular sub-base course (GSB).

TABLE 4.1: Low Volume Road Pavement

Sub-Grade (CBR %)	ESALs (x 1000) over Design Period		
	≤ 100	100 to 500	500 to 1000
▪ 5 to 12	40 mm BSC 200 mm CAB 150 mm GSB	50 mm BSC 200 mm CAB 150 mm GSB	50 mm BSC 250 mm CAB 150 mm GSB
▪ 12.1 to 20	40 mm BSC 200 mm CAB 100 mm GSB	50 mm BSC 200 mm CAB 100 mm GSB	50 mm BSC 200 mm CAB 150 mm GSB
▪ ≥ 20	40 mm BSC 200 mm CAB 100 mm GSB	50 mm BSC 200 mm CAB 100 mm GSB	50 mm BSC 200 mm CAB 100 mm GSB

4.2 Heavy Duty Pavements for Special Applications

Pavements that need to support either sustained heavy loads or channelised repeated load applications that are well in excess of traditional traffic loading patterns should be designed using a mechanistic design methodology in conjunction with special paving materials that offer high strength and stiffness under both dynamic and static loading conditions.

Design programs listed in Sub-Section 3.4 of this Manual can be used for heavy duty pavement design. If *Asphalt Institute SW-1* is used, it should be run in the *Advanced Structural Analysis Mode (DAMA)*; alternatively, the methodology described in *MS 23: Heavy Equipment (*also contained in the program CD *SW-1)* can be used. For strategically important projects, sufficient resources and time should be set aside to allow design analysis using different methodologies and materials.

In addition to heavy duty polymer modified or fibre reinforced asphalt mixtures, thick layers of cement stabilized granular material or special paving materials such as semi-rigid paving material (also termed Resin Modified Pavement or RMP) should be considered for such pavements. Pavement design should preferably be carried out in close cooperation with a supplier of special paving materials, to ensure that such paving materials are appropriately characterized. In addition, mechanistic testing of paving materials used in the design is strongly recommended; selected test parameters should be representative of environment and loading conditions to which the pavement will be exposed.

SECTION 5: WORKED EXAMPLES

5.0 WORKED EXAMPLES

5.1 <u>Traditional Pavement with Granular Base</u>

Design a road pavement for a 2-lane highway with an average daily traffic of 1350 vehicles, 16% of which are commercial vehicles with an un-laden weight > 1.5 tons.

<u>Step 1</u>: Development of Design Input

Traffic count data indicate a total of 2700 vehicles in both directions; pavement design is then based on 1350 vehicles (one direction, 24 hour period). If the design is based on traffic data from an HPU survey, the result based on a 16- hour survey (usually 06:00 to 22:00 hours) should be multiplied with 1.2.

The following additional project related information is available: -

PCV = 16 % (no detailed break-down by vehicle type)

Lane Distribution Factor, L = 1.0 (one lane in one direction)

Terrain Factor, T = 1.1 (rolling)

Design Life = 20 years

Annual Traffic Growth = 4.0%

<u>Step 2</u>: Determine Design Traffic (Traffic Category)

$ESAL_{Y1}$ (Base Year) = ADT x 365 x P_{CV} x LEF x L x T

= 1350 x 365 x 16/100 x 3.5 x 1.0 x 1.1

= 0.304 million

Design Traffic over 20 Years; $ESAL_{DES}$ = $ESAL_{Y1}$ x TGF

= 0.304 x 29.78

= **9.05 million**

= **Traffic Category T 3**

Step 3: Determine Sub-Grade Strength (Sub-Grade Category)

Results from Sub-Grade testing: -

CBR Mean	=18.5%
CBR Standard Deviation	= 4.4%
Probability 85% (Normal Deviate	= 1.282)

Characteristic CBR value used for design;

= 18.5% – 1.282 x 4.4%

= 18.5% – 5.6%

= 12.9%

= **Sub-Grade Category SG 2**

Step 4: Select one of the pavement structures from **Figure 3.3** (T 3, SG 2)

- Conventional flexible with unmodified bitumen;
  - Bituminous Surface Course (AC 10 or AC 14): 50 mm
  - Bituminous Binder Course/Road Base (AC 28): 130 mm
  - Crushed Aggregate RoadBase: 200mm
  - Granular Sub-Base: 200 mm

5.2 Full-Depth Asphalt Pavement

Design a road pavement for a 4-lane freeway (concession toll-road) with an average daily traffic of 7286 vehicles, of which 20% are commercial vehicles with an un-laden weight > 1.5 tons.

Step 1: Development of Design Input

ADT based on HPU survey (from 06:00 to 22:00 hours);

- CV 1 = 624 x 1.2 = 749 vehicles per 24-hour period
- CV 2 = 456 x 1.2 = 547 vehicles per 24-hour period
- CV 3 = 316 x 1.2 = 379 vehicles per 24-hour period
- CV 4 = 102 x 1.2 = 121 vehicles per 24-hour period

Lane Distribution Factor, L = 0.9 (two lanes in one direction)

Terrain Factor, T = 1.0 (flat)

Design Life, n = 20 years

Assumed Annual Traffic Growth Rate, r = 4.5%

Step 2: Determine Design Traffic (Traffic Category)

$ESAL_{Y1}$ (Base Year) = $(ADT_{CV1} \times LEF_1) + (ADT_{CV2} \times LEF_2) +$

$(ADT_{CV3} \times LEF_3) + (ADT_{CV4} \times LEF_4) \times 365 \times L \times T$

$= (749 \times 0.1) + (547 \times 4.0) + (379 \times 4.4) + (121 \times 1.8) \times 365 \times 0.9 \times 1.0$

= 1.363 million

Design Traffic over 20 Years;

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

= 1.363 million x 31.37 = **42.7 million**

= **Traffic Category T 5**

Step 3: Determine Sub-Grade Strength (Sub-Grade Category)

Results from Sub-Grade testing: -

Mean Modulus (H-FWD) = 165 MPa

Standard Deviation (H-FWD) = 28 MPa

Reliability 95% (Normal Deviate = 1.645)

Characteristic Sub-Grade Modulus value used for design:

= 165 MPa – (1.645 x 28 MPa)

= 165 MPa – 46 MPa

= **119 MPa**

= **Sub-Grade Category SG 3**

Note: Use design input value from Table 2.6 equal to:

(119 + 165)/2 ~ 140)

Step 4: Select one of the pavement structures from **Figure 3.5** (T 5, SG 3)

- **OPTION 1: Conventional flexible pavement with unmodified bitumen and granular base:**
  - Bituminous Surface Course (AC 10 or AC 14): 50 mm
  - Bituminous Binder Course/Road Base (AC 28): 190 mm
  - Crushed Aggregate Road Base: 200 mm
  - Granular Sub-Base: 150 mm

- **OPTION 2: Full-Depth Asphalt Pavement with unmodified bitumen:**
  - Bituminous Surface Course (AC 10 or AC 14): 50 mm
  - Bituminous Binder Course and Road Base: 200 mm
    - Bituminous Binder Course (AC 28): 60 mm
    - Bituminous Road Base (AC 28): 140 mm
  - Granular Sub-Base: 150 mm

  Note: *If asphalt binder and base course mixtures are based on the same type of binder and aggregate gradation, the thickness of binder and base course are interchangeable, that is, instead of 6 cm binder course and 14 cm base course, 10 cm binder course and 10 cm base course can be selected.*

- **OPTION 3: Use 40 mm polymer modified SMA 14 instead of 50 mm unmodified AC 10 or AC 14**

5.3 Low Volume Road

Design a pavement for a 2-lane rural road in a hilly setting. Assume a design period of 10 years. The volume of commercial traffic is less than 100 CV with an un-laden weight > 1.5 tons per day (one direction); the traffic volume over the design period is between 100 to 500 thousand CV (see **Table 4.1**)

Step 1: Development of Design Input

$ESAL_{DES}$: > 100 000 and < 500 000

CBR: 5 to 12%

OPTION 1: Select from **Table 4.1**

- Bituminous Surface Course (AC 10 or AC 14): 50 mm
- Crushed Aggregate Road Base: 200 mm
- Granular Sub-Base: 150 mm
-

OPTION 2: Select conventional flexible pavement with granular base from **Figure 3.1** (T 1, SG 1)

- Bituminous Surface Course (AC 10 or AC 14): 50 mm
- Crushed Aggregate Road Base: 250 mm
- Granular Sub-Base: 150 mm

Consideration can be given to adjusting pavement structures for low volume roads based on local materials and practices if satisfactory performance records are available.