

FINAL PROJECT

**ALTERNATIVE FLEXIBLE PAVEMENT DESIGNS
WITH 2024 BINA MARGA AND DISTRESS
PREDICTION BY USING KENPAVE PROGRAM
(Case study: Peureulak – Bts KM 7+750 – 16+500 Road Segment, Langsa
City, East Aceh)**

**Submitted to Islamic University of Indonesia Yogyakarta to Meet the
Requirements to Obtain Bachelor Degree in Civil Engineering**



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**CIVIL ENGINEERING INTERNATIONAL PROGRAM
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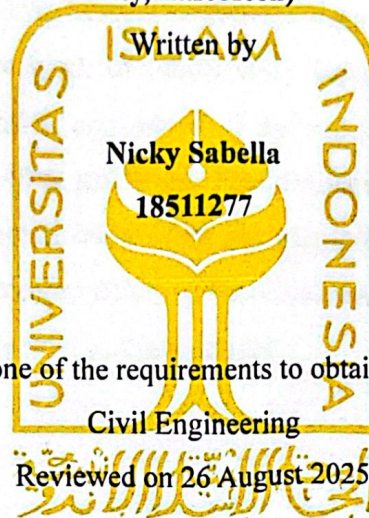
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City, East Aceh)



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PLAGIARISM STATEMENT

I hereby and solemnly declare that the Final Project report I compiled as a requirement to finish the Bachelor program at the Civil Engineering Department, Faculty of Civil Engineering and Planning in Islamic University of Indonesia is a writing I worked on by myself. Several references from the Final Project report which was quoted from the work of others were listed fully in the source in accordance to the norms, rules, and ethics of writing scientific papers. If it is discovered in the future that all or part of this Final Project report was not the result of my own work, or that there is found to be any plagiarism in certain sections, I am willing to accept any sanctions, including the revocation of my academic degree in accordance with applicable laws and regulations.

Yogyakarta, 26 August 2025

Statement Declarer



Nicky Sabella

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ABSTRACT

Road is an important infrastructure used to allow vehicles to move from one place to other places. Roads are facilitated with surface which are able to serve transportation under various conditions. For road to be able to serve traffic load it bears, a pavement planning and design approach are needed. The study is done to determine the alternative thickness design and investigate the stress and strain of the alternative pavement designs.

The study of the comparison of the alternative pavement designs to the Peureulak-Bts road in Langsa City, East Aceh refers to the method of 2024 Bina Marga which then is computed of the stress and strain values with the KENPAVE program with elastic linier approach.

The result shows that the three of the alternative pavement designs the author suggested, the service life that the alternative pavement design 1 exceeds 260 years of service life before the fatigue cracking occurs, 4 years before the rutting damage occurs and 15 years before the permanent deformation occurs. Meanwhile, the alternative pavement design 2 exceeds 211 years of service life before the fatigue cracking occurs, 8 years before the rutting damage occurs and 15 years before the permanent deformation occurs, and the alternative pavement design 3 exceeds 211 years of service life before the fatigue cracking occurs, 8 years before the rutting damage occurs and 29 years before the permanent deformation occurs. The further study needs to be conducted to execute the best possible alternative pavement design to the Peureulak-Bts road in Langsa city, East Aceh.

Keyword: Bina Marga 2024, Distress Prediction, KENPAVE, Service Life, Pavement Structure

PREFACE

Assalamu'alaikum Warahmatullahi Wabarakatuh,

All praise to the Almighty Allah SAW who has blessed the author with His grace and mercy that the author could finish this Final Project, within author's limits. The Final Project is one of the academic requirements to obtain the Bachelor Degree in Civil Engineering International Program Department in Faculty of Civil Engineering and Planning, Islamic University of Indonesia.

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Though this Final Project is never close to perfection due to author's limitations, the author sincerely hopes that the manuscript is useful for future uses.

Yogyakarta, 26 August 2025

Nicky Sabella

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LIST OF ABBREVIATIONS AND NOTATIONS

AC BC	= Asphalt Concrete Binder Course
AC WC	= Asphalt Concrete Wearing Course
CBR	= California Bearing Ratio
CESA	= Cumulative Equivalent Standard Axle
CTB	= Cement Treated Base
DD	= Directional Distribution
DL	= Lane Distribution
ESA	= Equivalent Standard Axle
ESAL	= Equivalent Standard Axle Load
HMA	= Hot Mix Asphalt
LFA	= <i>Lapisan Fondasi Atas</i> /Upper Foundation Layer
UR	= <i>Umur Rencana</i> /Service Life
VDF	= Vehicle Damage Factor

CHAPTER 1

INTRODUCTION

1.1 Background

Road is an important infrastructure used to allow vehicles to move from one place to another. Road pavements are facilitated with surface made of asphaltic or concrete material which are able to serve traffic load under various conditions such as heavy vehicle loads, varying weather conditions, moisture and water exposure. Good pavement design is the design that has the ability to withstand the damages on structural function such as fatigue cracking, rutting, and permanent deformation before reaching the service life (Hadi & Fauziah 2022).

Langsa city is one of the cities in Aceh Province, Indonesia. The highway road of Jalan Raya Medan – Banda Aceh, which is 2 lanes way in each direction undivided (2/2 UD), passed across throughout the entire city of Langsa, which makes the area strategic as road infrastructure has significant impact on the development of the city facilities as an activity hub. As the road structure of Jalan Raya Medan – Banda Aceh bears significant traffic loads, it inevitably undergoes several structural damages, such as Peureulak – Bts road section which is a part of Jalan Raya Medan – Banda Aceh.

As the *Satuan Kerja Perencanaan dan Pengawasan Jalan Nasional* (P2JN) investigated the Peureulak – Bts road extending from KM 7+750 – KM 16+500 in April 2023, the damages of the road structure were detected, such as potholes, distortion, cracking, and ravelling. The increase of traffic volume or the increase of axle loads of the vehicles causes a decline on structural functions of the road section due to the traffic loads which exceed the road capacity (Fiqri, 2024).

Fiqri (2024) conducted a study on the same location in Peureulak – Bts road section by designing the overlay pavement thickness using Bina Marga 2024. The secondary data in this study referred to the same secondary data obtained from

Satker P2JN in the mentioned study. Zuasri (2024) also studied the differences between Bina Marga 2017 and 2024 with the same secondary data.

This study focuses on proposing the best alternative design to Peureulak – Bts road section extending from KM 7+750 – KM 16+500 using the highest average daily traffic data taken in 2023 and according to the 2024 Highway Pavement Design Manual (*Bina Marga* 2024) and KENPAVE Program.

1.2 Research Questions

Based on the background explanation above, the research questions can be formulated as follows.

1. How are the alternative pavement designs to the Peureulak – Bts road according to *Bina Marga* 2024?
2. What are the stress and strain responses of the Peureulak – Bts road according to the average traffic data and *Bina Marga* 2024?
3. What is the distress of the alternative pavement design according to the average traffic data and *Bina Marga* 2024?
4. What is the best alternative pavement design for the Peureulak – Bts road according to the *Bina Marga* 2024 and KENPAVE Program?

1.3 Objectives of the Study

The objectives of the study are as follows.

1. To determine the alternative pavement designs to the Peureulak – Bts road.
2. To determine the stress and strain responses of the Peureulak – Bts road according to the average traffic data, *Bina Marga* 2024, and KENPAVE program.
3. To predict the distress of the alternative pavement designs according to the average traffic data, *Bina Marga* 2024, and KENPAVE program.
4. To determine the best alternative pavement design using *Bina Marga* 2024 and KENPAVE program.

1.4 Benefits of the Study

The benefits of the study are as follows.

1. It is hoped that the result of this study can be a reference for performance review to the related agencies.

2. It is hoped that the study is beneficial to the practitioners and the future researchers of the Civil Engineering study.

1.5 Limitations of the Study

To obtain the desirable result that will not deviate from the objectives of the study, there are limitations of this study as follows.

1. This study is conducted based on data obtained on Peureulak – Bts road KM 7+750 – 16+500 in Langsa City, East Aceh.
2. The analysis of pavement structure design is using the *Bina Marga* 2024.
3. The calculation of stress and strain which occurs due to traffic load is conducted with KENPAVE program.
4. The data obtained is a secondary data from Commitment Maker Office (PPK) of Working Unit of Planning and Inspection of National Road (*Satker P2JN*) of Aceh Province which is the average daily traffic (LHR) on Peureulak – Bts road KM 7+750 – 16+500 in Langsa City, East Aceh.

CHAPTER 2

LITERATURE REVIEW

2.1 Evaluation of Flexible Pavement Structure Design using KENPAVE Program

Tolab & Fauziah (2024) conducted a study on the flexible pavement structure of the Yogyakarta-Bawen Toll Road. The analysis in this study is using elastic and viscoelastic approaches with reference to *Bina Marga* 2017 and with the help of KENPAVE program. The study resulted with a proposed alternative flexible pavement design with an optimal elastic and viscoelastic approach which is of AC-WC 40 mm, AC-BC 60 mm, AC Base 180 mm, and LPA 300 mm. This design is chosen out of three proposed alternative design because the value of repetitive traffic loads, residual values, and pavement life predictions have bigger results in serving traffic loads than other design alternatives.

Hadi & Fauziah (2022) compared the service life between Superpave mix and AC-WC using viscoelastic and elastic approaches. Superpave is one of pavement type which consists of modified aggregate gradation developed by Strategic Highway Research Program (SHRP). According to previous researches conducted, Superpave mixture is proven to perform better in receiving or distributing vehicle loads and resistance to submersion conditions (Hadi & Fauziah, 2022). Hadi & Fauziah (2022) studied the stiffness modulus of bitumen and stiffness modulus of mixture (S_{mix}) with Ullidtz and Nottingham equation respectively, then continued to propose a new pavement design in reference to *Bina Marga* 2017 by collecting data of average daily traffic (LHRT). After the stiffness modulus and the new pavement design are obtained, both of the data will be combined and analysed by viscoelastic and elastic methods on KENPAVE program to determine the service life of the pavement, and the damage category in the start and the end that will happen in the specified amount of time. Based on the conducted study, it is obtained

that the Superpave pavement design indeed has the longer service life compared to AC-WC mix.

Kurniawan & Hadi (2024) conducted empirical and mechanistic – empirical method on the identification and evaluation of road pavement performance of Yogyakarta – Pulowatu road in Yogyakarta Special Region. In the empirical method, the alternative solution offered is Pavement Condition Index (PCI) and Surface Distress Index (SDI), while mechanistic – empirical method offered the analysis from KENPAVE program. The study resulted in the mechanistic method obtaining the PCI value of 31,68 (very poor) and SNI of 267,25 (severely damaged) and recommended to undergo major maintenance and road rehabilitation. In the mechanistic – empirical method, the existing design was identified not reaching its 20 years of service life and recommended to be redesigned using FFF6 criteria.

Cahyono et al. (2022) conducted an analysis on the remaining service life of flexible pavement according to the damage prediction with Mechanistic-Empirical Pavement Design Guide (MEPDG) AASHTO 2008 method. The study relied on Pavement Condition Index (PCI) value. The study focuses on three roads in Yogyakarta Special Region: Milir – Sentolo, Pakem – Prambanan, and North – West Arteries. The pavement responses were analyzed using KENPAVE program with input data of elasticity modulus of the materials. Remaining service life (RSL) predictions were based on the severity of the predicted damage. The analysis resulted in the Pakem – Prambanan road segment having the longest remaining service life, both based on the prediction of pavement damage and predicted PCI value due to the segment serving the least traffic compared to other segments.

Alfi et al. (2024) evaluated the remaining service life (RSL) of the flexible pavement structure on Milir – Sentolo road in Kulon Progo. The study aimed to investigate the structural damages that may happen during the RSL. The method used is mechanistic-empirical with KENPAVE and ELMOD 6.0 method to determine the elasticity modulus for every pavement layer. The primary and secondary data is obtained from Directorate of National Road Procurement – *Balai Besar Pelaksanaan Jalan Nasional (BBPJN)*. The elasticity modulus of HMA layer is 986,2 MPa, the base layer is 88,3 MPa, while the subgrade layer is 48 MPa. The

fatigue damage as much as 20.420.832 ESAL with remaining service life of 23 years. Rutting damage as much as 4.352.121 ESAL with remaining service life of 5 years, meanwhile the permanent deformation as much as 203.636 ESAL with the remaining service life of 0 year (failure). The study concluded that the Milir – Sentolo road will experience the permanent deformation before the first year of service life.

2.2 Analysis of Structural Response of Flexible Pavement by Viscoelastic and Elastic Approaches

Pambudi & Fauziah (2021) studied the flexible pavement of Simpang Pundu – Tumbang Samba road according to *Bina Marga* 2017 with elastic and viscoelastic approaches. The study resulted in the stress – strain responses from the four available designs which were evaluated using KENPAVE program, with elastic approach obtained the smaller stress value than viscoelastic approach. The stress in fatigue cracking with elastic approach is 0,000158 KPa, while the viscoelastic approach is 0,000159 KPa. Rutting damage with elastic approach is 0,000237 KPa, meanwhile the viscoelastic approach is 0,000238 KPa. The permanent deformation with elastic approach is 0,000234 KPa, meanwhile the viscoelastic approach is 0,000236 KPa. The study concluded that the service life using elastic approach has higher value than the service life using viscoelastic approach.

Zuasri & Fauziah (2024) analysed the flexible pavement of Peureulak-Bts road according to the average daily traffic data and compared the pavement design of *Bina Marga* 2017 and 2024 with elastic approach. The study resulted in the design of both *Bina Marga* 2017 and 2024 recommending flexible pavement with CTB and *LFA*, but compared to each other, the *Bina Marga* 2017 Manual focuses more on the cost while the *Bina Marga* 2024 focuses more on quality since the first damage happened in the flexible pavement using *Bina Marga* 2017.

Nasution & Fauziah (2024) conducted a study regarding the flexible pavement of Peureulak-Bts road according to the *Bina Marga* 2017 and 2024 with viscoelastic approach. The study resulted in the design of flexible pavement with CTB and *LFA* from both of *Bina Marga* 2017 and 2024, but with different result of thickness. The *Bina Marga* 2017 is proven to have small permanent deformation

value, although if the traffic load is higher than the secondary data used, the possibility of permanent deformation tends to happen faster, meanwhile for the *Bina Marga* 2024, it obtained the higher value of permanent deformation but the rutting and fatigue value is lesser due to the thinner pavement layer compared to *Bina Marga* 2017.

Fariyadin et al. (2025) studied to determine the thickness of flexible pavement layers and the types of flexible pavement using the *Bina Marga* 2017 on Darul Hikmah Road, Terong Tawah, Labuapi Regency in West Lombok. The secondary data needed in this study is the average daily traffic volume (*LHR*). The CESA4 value is 4.021.566,47 while the CESA5 value is 469.755.421 obtained from the calculation from the average daily traffic data. The study resulted in the recommended flexible pavement structure with AC-WC thickness of 4 cm, the AC-BC thickness of 6 cm, the AC Base of 10 cm, and the *LFA* class A (Granular Base Layer) of 40 cm.

2.3 Research Comparison

According to the previous studies that have been discussed, there are several similarities and differences in comparison with this study to be conducted. The summary of the previous studies discussed can be seen in the Table 2.1.

Table 2.1 Comparison of the Previous Studies

Author (Year)	Tolab & Fauziah (2024)	Hadi & Fauziah (2022)	Kurniawan & Hadi (2024)	Cahyono et al. (2022)	Alfi et al. (2024)	Pambudi & Fauziah (2021)	Zuasri & Fauziah (2024)	Nasution & Fauziah (2024)	Sabella & Fauziah (2024)
Title	Prediction of Damage and Remaining Life of Yogyakarta – Bawen Toll Road Pavement with Elastic and Viscoelastic Approaches	<i>Studi komparasi prediksi umur pelayanan antara campuran Superpave dan AC-WC menggunakan pemodelan viskoelastik dan elastik</i>	<i>Kolaborasi Metode Empiris dan Mekanistik- Empiris Guna Identifikasi dan Evaluasi Kinerja Perkerasan Jalan</i>	Analysis of the Remaining Service Life of Flexible Pavement Based on Damage Prediction with MEPDG Method and Prediction of Pavement Condition Values	<i>Analisis Prediksi Umur Sisa Struktur Perkerasan Lentur Menggunakan Metode Mekanistik- Empirik pada Jalan Milir- Sentolo Ruas Timur</i>	<i>Evaluasi Perancangan Struktur Perkerasan dengan Metode Bina Marga 2017 dan Program KENPAVE Menggunakan Pendekatan Elastik dan Viskoelastik</i>	<i>Komparasi Alternatif Desain Perkerasan Lentur Metode Bina Marga 2017 dan 2024 Menggunakan KENPAVE (Studi Kasus: Ruas Jalan Peumeulak Aceh Timur (STA 7+750 – STA 16+500))</i>	<i>Analisis Kerusakkan Perkerasan Lentur dengan Pedoman Bina Marga 2017 dan 2024 Menggunakan Metode Viscoelastic di Jalan Peureulak, Aceh Timur</i>	Alternative Flexible Pavement Designs with 2024 Bina Marga and Distress Prediction by Using KENPAVE Program

Continuation of Table 2.1 Comparison of the Previous Studies

Author (Year)	Tolab & Fauziah (2024)	Hadi & Fauziah (2022)	Kurniawan & Hadi (2024)	Cahyono et al. (2022)	Alfi et al. (2024)	Pambudi & Fauziah (2021)	Zuasri & Fauziah (2024)	Nasution & Fauziah (2024)	Sabella & Fauziah (2024)
Research Methods	2017 Highway Pavement Design Manual (<i>Bina Marga 2017</i>)	2017 Highway Pavement Design Manual (<i>Bina Marga 2017</i>)	2017 Highway Pavement Design Manual (<i>Bina Marga 2017</i>)	AASHTO 2008	2017 Highway Pavement Design Manual (<i>Bina Marga 2017</i>)	2017 Highway Pavement Design Manual (<i>Bina Marga 2017</i>)	2017 and 2024 Highway Pavement Design Manual (<i>Bina Marga 2017 and 2024</i>)	2017 and 2024 Highway Pavement Design Manual (<i>Bina Marga 2017 and 2024</i>)	2024 Highway Pavement Design Manual (<i>Bina Marga 2024</i>)
Research Approaches	Elastic and Viscoelastic Approaches	Elastic and Viscoelastic Approaches	Elastic Approach	PCI Value	Deflection Basin Fit	Elastic and Viscoelastic Approaches	Elastic Approach	Viscoelastic Approach	<i>Bina Marga 2024</i>
Location	Yogyakarta – Bawen Toll Road	-	Yogyakarta – Pulowatu Road	Milir – Sentolo, Pakem – Prambanan, North West Arteries	Milir – Sentolo East Road	Simpang Pundu – Tumbang Samba	Peureulak road, East Aceh	Peureulak road, East Aceh	Peureulak road, East Aceh

Continuation of Table 2.1 Comparison of the Previous Studies

Author (Year)	Tolab & Fauziah (2024)	Hadi & Fauziah (2022)	Kurniawan & Hadi (2024)	Cahyono et al. (2022)	Alfi et al. (2024)	Pambudi & Fauziah (2021)	Zuasri & Fauziah (2024)	Nasution & Fauziah (2024)	Sabella & Fauziah (2024)
Result	The study resulted with a proposed alternative flexible pavement design with an optimal elastic and viscoelastic approach which is of AC-WC 40 mm, AC-BC 60 mm, AC Base 180 mm,	Based on the conducted study, it is obtained that the Superpave pavement design indeed has the longer service life compared to AC-WC mix.	The study resulted in the mechanistic method obtaining the PCI value of 31,68 (very poor) and SNI of 267,25 (severely damaged) and recommended to undergo major maintenance and road rehabilitation.	The analysis resulted in the Pakem-Prambanan road segment having the longest remaining service life, both based on the prediction of pavement damage	The study concluded that the Milir – Sentolo road will experience the permanent deformation before the first year of service life.	The study concluded that the service life using elastic approach has higher value than the service life using viscoelastic approach.	The study resulted in the design of both 2017 and 2024 Highway Pavement Design Manual recommending flexible pavement with CTB and <i>LFA</i> , but compared to each other, the 2017 Highway Pavement Design Manual focuses more on	The 2017 Highway Pavement Design Manual is proven to have small permanent deformation value, although if the traffic load is higher than the secondary data used, the possibility of permanent deformation	The service life that the alternative pavement design 1 exceeds 260 years of service life before the fatigue cracking occurs, 4 years before the rutting damage occurs and 15 years before the permanent deformation occurs.

Continuation of Table 2.1 Comparison of the Previous Studies

Author (Year)	Tolab & Fauziah (2024)	Hadi & Fauziah (2022)	Kurniawan & Hadi (2024)	Cahyono et al. (2022)	Alfi et al. (2024)	Pambudi & Fauziah (2021)	Zuasri & Fauziah (2024)	Nasution & Fauziah (2024)	Fariyadin et al. (2025)
Result	and LPA 300 mm. This design is chosen out of three proposed alternative design because the value of repetitive traffic loads, residual values, and pavement life predictions have bigger results in serving traffic loads than other design alternatives.		In the mechanistic – empirical method, the existing design was identified not reaching its 20 years of service life and recommended to be redesigned using FFF6 criteria.	and predicted PCI value due to the segment serving the least traffic compared to other segments.		.	the cost while the 2024 Highway Pavement Design Manual focuses more on quality since the first damage happened in the flexible pavement using 2017 Highway Pavement Design Manual.	tends to happen faster, meanwhile for the 2024 Highway Pavement Design Manual, it obtained the higher value of permanent deformation but the rutting and fatigue value is lesser due to the thinner pavement layer compared to 2017 Highway Pavement Design Manual.	

From Table 2.1 above, there are some similarities and differences between this study and the previous studies which are as follows.

1. The similarity between this study and Zuasri & Fauziah, (2024) is that this study analyses the flexible pavement design with 2024 Highway Pavement Design Manual (*Bina Marga* 2024). However, this study focuses on the 2024 version of Highway Pavement Design rather than comparing it to the 2017 Highway Pavement Design Manual (*Bina Marga* 2017). This study will also analyse the structure of flexible pavement design using elastic and viscoelastic approaches.
2. The similarity between this study and Nasution & Fauziah (2024) is that this study analyses the flexible pavement design with 2024 Highway Pavement Design Manual (*Bina Marga* 2024). However, this study focuses on the 2024 version of Highway Pavement Design rather than comparing it to the 2017 Highway Pavement Design Manual (2017 *Bina Marga*). This study will also analyse the structure of flexible pavement design using elastic and viscoelastic approaches.
3. The similarity between this study and Zuasri & Fauziah (2024) is that the location of the study and the secondary data needed in both of the studies are the same, but this study will focus more on the structural condition such as stress and strain responses of the flexible pavement design according to the 2024 Highway Pavement Design Manual.
4. The similarity between this study and Nasution & Fauziah (2024) is that the location of the study and the secondary data needed in both of the studies are the same, but this study will focus more on the structural condition such as stress and strain responses of the flexible pavement design according to the 2024 Highway Pavement Design Manual.

CHAPTER 3

THEORETICAL BACKGROUND

3.1 Pavement Design using the *Bina Marga 2024* Method

Several indicators and data are needed to analyse the pavement thickness to design the pavement which are as follows.

3.1.1 Service Life

There is a service life to be determined in designing the road pavement. The life plan should consider the road capacity. Below on Table 3.1 is the service life of the new pavement design according to *Bina Marga 2024*.

Table 3.1 Service Life of New Pavement Design (*UR*)

Pavement Type	Element of the Pavement	Life Plan (Years)
Flexible Pavement	Asphaltic and grainy layers	20
	Road foundation layer	40
	All pavement in areas which overlay is not possible to do, such as: highway, underpass, bridge, and tunnels	
	Cement Treated Base (CTB)	
Rigid Pavement	Upper layer foundation, lower layer foundation, cement pavement layer, and road foundation	
Road without cover	All elements (including road foundation)	10

(Source: Bina Marga 2024)

3.1.2 Selection of Pavement Structure

The selection of pavement structure is varied according to traffic volume, life plan, and road foundation condition. The limitation on Table 3.2 is not absolute, the technician should consider the lowest cost during the life plan, limitation, and practicality of the implementation. The alternative design selection according to the manual should be based on the lowest discounted lifecycle cost.

Table 3.2 Pavement Type Selection

Pavement	Design Chart	ESA5 (million) in 20 years				
		0-1	1-4	4-10	>10-30	>30
AC Modification	3, 3A, 3B	-	-	-	-	2
AC with CTB					2	-
AC Modification with CTB					-	2
AC with aggregate foundation layer	3, 3A, 3B	-	1, 2	1, 2	2	-
Thin HRS above aggregate foundation layer	4	2	2	-	-	-
Double layer asphalt aggregate layer (<i>Burda</i>) or one layer asphalt-aggregate layer (<i>Burtu</i>) with aggregate foundation layer	5	3	3	-	-	-

(Source: Bina Marga 2024)

Continuation of Table 3.2 Pavement Type Selection

Pavement	Design Chart	ESA5 (million) in 20 years				
		0-1	1-4	4-10	>10-30	>30
AC/HRS with Soil Cement foundation layer	6	2	2	-	-	-
AC/HRS with aggregate foundation layer and the soil base improvement (with cement stabilization)	7	2	2	-	-	-
Rigid pavement with heavy traffic	8	-	-	-	2	2
Rigid pavement with low traffic	8A	-	-	1, 2	-	-
Pavement without cover (<i>Japat</i> and gravel road)	9	1	-	-	-	-

(Source: Bina Marga 2024)

Note:

Difficulty level:

1 – small – medium contractor

2 – big contractor with adequate resources

3 – need special expertise and expert technician – contractor specializing in *Burtu/Burda***3.1.3 Traffic Volume**

The important parameter in structural analysis of pavement is the traffic data that is needed to calculate the planned traffic load the pavement will bear during the service life. The load is calculated from the traffic volume from the survey year which then to be projected throughout the service life. The first-year volume is the traffic volume throughout the first year after the pavement is finished constructing or rehabilitating. The main element of traffic load in designs are traffic volume for every class of vehicle and axle load for commercial vehicles in Equivalent Standard

Axle Load (ESAL). Other than average traffic data, those parameters below are needed to determine the traffic volume to design the pavement.

1. Traffic growth factors

Traffic growth should be according to the historical growth data or correlation formulation with the other growth formulation which is valid. If there is no traffic growth data, those figures in can be used in the following Table 3.3 below.

Table 3.3 Traffic Growth Rate (i), %

	Java	Sumatera	Kalimantan	Indonesia Average
Arterial and highway	4,80	4,83	5,14	4,75
Rural collector	3,50	3,50	3,50	3,50
Village road	1,00	1,00	1,00	1,00

(Source: Bina Marga 2024)

Traffic growth throughout the service life is calculated with cumulative growth factor as follows.

$$R = \frac{(1+0,01 i)^{UR}-1}{0,01 i} \quad (3.1)$$

with:

R = Multiplication factor of cumulative growth factor,

i = Annual traffic growth rate (%), and

UR = Service life (years).

If it is predicted that there will be the difference in yearly growth rate throughout the service life, with $i_1\%$ during the first period (UR_1 year) and $i_2\%$ throughout the next remaining service life ($UR - UR_1$), the multiplication factor of cumulative traffic growth can be calculated using the formula as follows.

$$R = \frac{(1+0,01i_1)^{UR_1}-1}{0,01i_1} + (1 + 0,01 i_1)^{(UR_1-1)}(1 + 0,01i_2)\left\{\frac{(1+0,01i_2)^{(UR-UR_1)}-1}{0,01i_2}\right\} \quad (3.2)$$

with:

R = Multiplication factor of cumulative growth factor,

i_1 = Annual traffic growth rate of period 1 (%),

i_2 = Annual traffic growth rate of period 2 (%),

UR = Service life (years), and

UR_1 = Service life of period 1 (years).

2. Traffic on Planned Lanes

For two-way traffic lanes, the lane directional distribution factor (DD) is generally 0,50 except in the location where the number of commercial vehicles tend to be higher in one specific lane. Lane distribution factor (DL) is used to adjust to the cumulative load (CESAL) on the road with two or more lanes in one direction. In the mentioned road, even though most of the commercial vehicles probably will use the outer lane, some of them will use inner lanes. The lane distribution needs to be according to the traffic survey data in the specified location, if unavailable, it can use Table 3.4 as follows.

Table 3.4 Lane Distribution Factor (DL)

Total Lanes in Each Direction	Commercial Vehicles in Planned Lanes (% to the Commercial Vehicles Population)
1	100
2	80
3	60
4	50

(Source: Bina Marga 2024)

3. Vehicle Damage Factor

In designing pavement, the traffic load is converted to standard load (ESA) by using the vehicle damage factor. Vehicle Damage Factor (VDF) from a specified vehicle is the total of ESA load to all the group of the specified vehicle axle. By using VDF, the traffic load which is the collection of all vehicle kinds from various classes with multiple configuration and axle can be converted to be total load of ESA. The structural analysis of the pavement is done according to the

total cumulative of ESA load in planned lanes throughout the service life obtained from the VDF value.

Accurate design needs accurate traffic load calculation. Studi or axle load survey which is well-designed and well-implemented is the base of good of ESA calculation. Therefore, the axle load survey should be done if possible. The data collection of axle load can be seen in the Table 3.5 as follows.

Table 3.5 Data Collecting of Axle Load

Specification of Road Facilities	Axle Load Data Source
Freeway Road*	1 or 2
Highway	1 or 2 or 3
Medium Road	2 or 3
Small Road	2 or 3

(Source: Bina Marga 2024)

*Data of axle load is obtained from:

1. Weighbridge, static weighbridges or WIM (direct survey)
2. Axle load survey on weighbridge or WIM that is done and declared representing
3. WIM Regional data which is published by *Ditjen Bina Marga*

The study is done in Aceh province, hence the VDF value used is in the Table 3.6 as follows.

Table 3.6 Vehicle Damage Factor in Aceh and North Sumatera Province

Vehicle Class	Condition			
	VDF 4		VDF 5	
5B	1,2	1,2	1,3	1,3
6A	0,5	0,5	0,4	0,4
6B	1,6	0,4	2,2	0,4
7A1	10,1	3	17,2	3,4
7A2	10,2	3,9	19,7	5,2
7A3	-	-	-	-

Continuation of Table 3.6 Vehicle Damage Factor in Aceh and North Sumatra Province

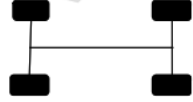
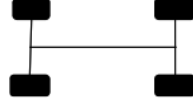
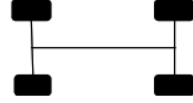
Vehicle Class	Condition			
	VDF 4		VDF 5	
7B1	-	-	-	-
7B2	-	-	-	-
7B3	-	-	-	-
7C1	8,2	5,7	11,9	7,2
7C2A	6,6	5,6	9,2	7,2
7C2B	11,1	6,8	19,5	9,6
7C3	16	9	29,4	12,8
7C4	-	-	-	-

(Source: Bina Marga 2024)

4. Class Distribution of Commercial Vehicles

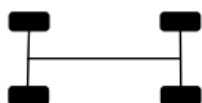
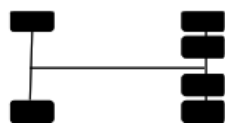
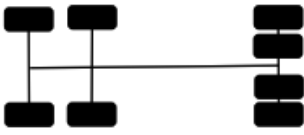
The traffic load of rigid pavement is based on the axle group of commercial vehicles (*Jumlah Total Sumbu Kendaraan Niaga, JSKN*) and not according ESA value. Below on Table 3.7 is the classification and configuration of the axle load of commercial vehicles.

Table 3.7 Classification and Configuration of Vehicle Axle Load

Classification of Vehicle	Description	Axis Configuration	Axis Classification	Configuration Scheme	
1	Motorcycles and 3-wheels vehicles				
2	Light vehicles – sedan, jeep, and station wagon	1.1	2		
3	Light vehicles – medium micro-trans	1.1	2		
4	Light vehicles – pick up, micro truck	1.1	2		

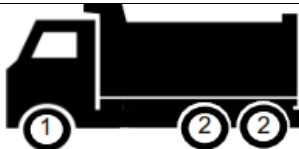
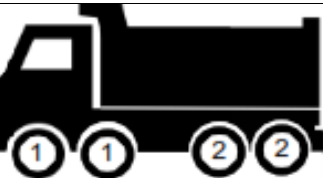
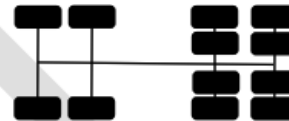
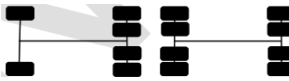
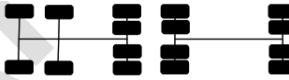
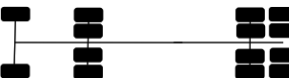
(Source: Bina Marga 2024)

Continuation of Table 3.7 Classification and Configuration of Vehicle Axle Load

Classification of Vehicle	Description	Axis Configuration	Axis Classification	Configuration Scheme	
5A	Small buses	1.1	2		
5B	Big buses	1.2	2		
6A	Truck with 2 axle – light truck	1.1	2		
6B	Truck with 2 axle – medium truck	1.2	2		
7A1	Truck with 3 axles	11.2	2		

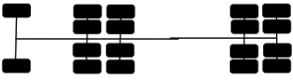
(Source: Bina Marga 2024)

Continuation of Table 3.7 Classification and Configuration of Vehicle Axle Load

Classification of Vehicle	Description	Axis Configuration	Axis Classification	Configuration Scheme	
7A2	Truck with 3-axis	1.22	2		
7A3	Truck with 4-axis	11.22	2		
7B1	Truck with 4-axis	1.2+2.2	4		
7B2	Truck with 5-axis	11.2+2.2	4		
7C1	Truck with 4-axis	1.2-22	3		

(Source: Bina Marga 2024)

Continuation of Table 3.7 Classification and Configuration of Vehicle Axle Load

Classification of Vehicle	Description	Axis Configuration	Axis Classification	Configuration Scheme	
7C2A	Truck with 5-axis	1.22-22	3		
7C2B	Truck with 5-axis	1.22-222	3		
7C3	Truck with 6-axis	1.22-222	3		
7C4	Truck with 7-axis	1.22-2222	3		
8	Non-motorized vehicles				

(Source: Bina Marga 2024)

5. Cumulative Equivalent Standard Axle Load (CESAL)

Cumulative Standard Axle Load is a total cumulative axle traffic load design in the design lane throughout the service life, which is determined as follows.

Using VDF of each commercial vehicle,

$$CESAL = (\Sigma LHR_{JK} \times VDF_{JK}) \times 365 \times DD \times DL \times R \quad (3.3)$$

with:

- LHR_{JK} = Average daily traffic each commercial vehicle (unit vehicle per day),
- VDF_{JK} = Vehicle Damage Factor each commercial vehicle, ... appendix 1,
- DD = Directional Distribution Factor,
- DL = Lane Distribution Factor,
- CESAL = Cumulative Standard Axle Load throughout the service life, and
- R = Cumulative traffic growth factor.

3.1.4 Flexible Pavement Thickness Design

Pavement design according to the planned traffic load can be chosen by the materials used as follows.

1. Design Chart-3(1) Flexible Pavement Design with 150 mm CTB
2. Design Chart-3(2) (with 200 mm CTB)
3. Design Chart-3(3) (with 250 mm CTB)
4. Design Chart-3(4) (with 300 mm CTB)
5. Design Chart-3A Flexible Pavement Design – Asphalt with Aggregate Foundation Layer (Asphalt Pen 60/70 and PG70)
6. Design Chart-3B Fill Layer Thickness Adjustment of Coarse Grain or *LFA* C Class or Cement Stabilization (Only for Design Chart-3A)
7. Design Chart-4 Flexible Pavement with HRS
8. Design Chart-5 Grained Pavement with Coating

9. Design Chart-6 Pavement with Soil Cement Stabilization

10. Design Chart-7 Pavement with Soil Cement Subgrade Improve

Other alternatives can be chosen in accordance to the site condition. However, it is suggested to use the design chart as the first step for all designs.

Pavement Thickness Design is based on the ESA value of 4 and 5 depending on the damages model and the design approaches that are being used. The ESA value used is in accordance to the specified input that is used in the designing process.

1. Value 4 is used for design chart with thin coating (like *Burtu* or *Burda*), unsealed granular pavement, and overlay thickness design based on bending graph for permanent deformation criteria.
2. Value 5 is used for flexible pavement design (in accordance to the asphalt cement yielding factor in design with mechanistic-empirical approach).
3. Rigid pavement uses the number of group and distribution of vehicle axle load distribution (*JSKN*), not with ESA value as unit of traffic load for concrete pavement.

Pavement thickness for flexible pavement is based on the CESAL value for the service life according to the 2024 Highway Pavement Design Manual. In this study, the design chart used is 3, 3A, and 3B. The following are the pavement thickness design charts in the Table 3.8, Table 3.9, Table 3.10, Table 3.11, Table 3.12, Table 3.13, and Table 3.14.

Table 3.8 Design Chart-3(1) Flexible Pavement Design with 150 mm CTB (asphalt pen 60/70 and PG70)

	PAVEMENT STRUCTURE									
	F(1) 1	F(1) 2	F(1) 3	F(1) 4	F(1) 5	F(1) 6	F1 (7)	F1 (8)	F1 (9)	F1 (10)
	For planned load < 30 million ESA5 using Asphalt Pen 60-70				For planned load ≥ 30 million ESA5 is recommended using Asphalt PG70 ⁽³⁾					
Service life 20 years (10 ⁶ ESA5)	> 1-6	>6-10	>10-20	>20-30	>30-40	>40-50	>50-80	>80-100	>100-150	>150-200
Type of binder surface	AC									
Type of foundation layer	Cement Treated Base (CTB)									
Pavement Thickness (mm)										
AC WC	40	40	50	40	40	40	40	50	40	40
AC BC	60	75	80	65	60	60	80	80	60	60
	-	-	-	70	-	-	-	-	-	-
AC Base ⁽¹⁾	150	150	150	150	150	150	150	150	150	150
Aggregate Foundation Layer B Class	150	150	150	150	150	150	150	150	150	150
Selected Coarse Grained Fill or <i>LFA</i> C Class or Cement Stabilization ⁽²⁾	200	200	200	200	200	200	200	200	200	200

(1) For AC Base with planned traffic load more than 30 million ESA5 may not use asphalt PG70

(2) Can use selected coarse-grained fill which has minimum of 30% CBR with PI 6-15 and maximum grain size of 50 mm or LFA C Class or cement stabilization (UCS 10kg/cm²). If these three of the materials or the equipment cannot be granted, this layer will be *LFA* B Class with the thickness of 200 mm if the price is the same or lower than those three materials.

(3) Only for AC WC and AC BC

(Source: Bina Marga 2024)

Table 3.9 Design Chart 3(2) Flexible Pavement Design with 200 mm CTB (asphalt pen 60/70 and PG70)

	PAVEMENT STRUCTURE							
	F(2) 1	F(2) 2	F(2) 3	F(2) 4	F(2) 5	F(2) 6	F(2) 7	F(2) 8
	For planned traffic load < 30 million ESA5 using Asphalt Pen 60-70			For planned traffic load ≥ 30 million ESA5 is recommended using Asphalt PG70 ⁽³⁾				
Service life for 20 years (10 ⁶ ESA5)	>1-8	>8-15	>15-30	>30-50	>50-75	>75-95	>95-150	>150-200
Type of binder surface	AC							
Type of foundation layer	Cement Treated Base (CTB)							
Pavement Thickness (mm)								
AC WC	40	50	50	40	40	40	50	40
AC BC	60	70	80	70	60	70	80	60
	-	-	-	70	-	-	-	-
AC Base ⁽¹⁾	-	-	-	-	100	100	100	75
	-	-	-	-	-	-	-	75
CTB	200	200	200	200	200	200	200	200
Aggregate Foundation Layer B Class	150	150	150	150	150	150	150	150
Selected Coarse Grained Fill or <i>LFA</i> C Class or Cement Stabilization ⁽²⁾	200	200	200	200	200	200	200	200

(1) For AC Base with planned traffic load more than 30 million ESA5 may not use asphalt PG70

(2) Can use selected coarse-grained fill which has minimum of 30% CBR with PI 6-15 and maximum grain size of 50 mm or LFA C Class or cement stabilization (UCS 10kg/cm²). If these three of the materials or the equipment cannot be granted, this layer will be LFA B Class with the thickness of 200 mm if the price is the same or lower than those three materials.

(3) Only for AC WC and AC BC

(Source: Bina Marga 2024)

Table 3.10 Design Chart 3(3) Flexible Pavement Design with 250 mm CTB (asphalt pen 60/70 and PG700)

	PAVEMENT STRUCTURE						
	F(3) 1	F(3) 2	F(3) 3	F(3) 4	F(3) 5	F(3) 6	F(3) 7
	For planned traffic load < 30 million ESA5 using Asphalt Pen 60-70			For planned traffic load ≥ 30 million ESA5 is recommended using Asphalt PG70 ⁽³⁾			
Service life for 20 years (10 ⁶ ESA5)	>1-9	>9-15	>15-30	>30-50	>50-75	>75-110	>110-200
Type of binder surface	AC						
Type of foundation layer	Cement Treated Base						
Pavement Thickness							
AC WC	40	40	50	40	40	40	40
AC BC	60	70	80	60	70	65	80
	-	-	-	70	-	-	-
AC Base ⁽¹⁾	-	-	-	-	80	100	100
	-	-	-	-	-	-	-
CTB	250	250	250	250	250	250	250
Aggregate Foundation Layer B Class	150	150	150	150	150	150	150
Selected Coarse Grained Fill or <i>LFA</i> C Class or Cement Stabilization ⁽²⁾	200	200	200	200	200	200	200

(1) For AC Base with planned traffic load more than 30 million ESA5 may not use asphalt PG70

(2) Can use selected coarse-grained fill which has minimum of 30% CBR with PI 6-15 and maximum grain size of 50 mm or *LFA* C Class or cement stabilization (UCS 10kg/cm²). If these three of the materials or the equipment cannot be granted, this layer will be *LFA* B Class with the thickness of 200 mm if the price is the same or lower than those three materials.

(3) Only for AC WC and AC BC

(Source: Bina Marga 2024)

Table 3.11 Design Chart 3(4) Flexible Pavement Design with 300 mm CTB (asphalt pen 60/70 and PG700)

	PAVEMENT STRUCTURE							
	F(4) 1	F(4) 2	F(4) 3	F(4) 4	F(4) 5	F(4) 6	F(4) 7	F(4) 8
	For planned traffic load < 30 million ESA5 using Asphalt Pen 60-70			For planned traffic load ≥ 30 million ESA5 is recommended using Asphalt PG70 ⁽³⁾				
Service life for 20 years (10 ⁶ ESA5)	>1-10	>10-17	>17-30	>30-40	>40-60	>60-90	>90-150	>150-200
Type of binder surface	AC							
Type of foundation layer	Cement Treated Base (CTB)							
Pavement Thickness (mm)								
AC WC	40	40	50	50	40	50	50	40
AC BC	60	70	75	80	60	60	60	75
	-	-	-	-	70	-	-	-
AC Base ⁽¹⁾	-	-	-	-	-	80	100	100
	-	-	-	-	-	-	-	-
CTB	300	300	300	300	300	300	300	300
Aggregate Foundation Layer B Class	150	150	150	150	150	150	150	150
Selected Coarse Grained Fill or <i>LFA</i> C Class or Cement Stabilization ⁽²⁾	200	200	200	200	200	200	200	200

(1) For AC Base with planned traffic load more than 30 million ESA5 may not use asphalt PG70

(2) Can use selected coarse-grained fill which has minimum of 30% CBR with PI 6-15 and maximum grain size of 50 mm or *LFA* C Class or cement stabilization (UCS 10kg/cm²). If these three of the materials or the equipment cannot be granted, this layer will be *LFA* B Class with the thickness of 200 mm if the price is the same or lower than those three materials.

(3) Only for AC WC and AC BC

(Source: Bina Marga 2024)

Table 3.12 Desin Chart-3A Flexible Pavement Design – Asphalt with Aggregate Foundation Layer (asphalt pen 60/70 and PG70)

	PAVEMENT STRUCTURE								
	FFF(1) 1	FFF(1) 2	FFF(1) 3	FFF(1) 4	FFF(1) 5	FFF(1) 6	FFF(1) 7	FFF(1) 8	FFF(1) 9
	For planned traffic load < 30 million ESA5 using Asphalt Pen 60-70					For planned traffic load ≥ 30 million ESA5 is recommended using Asphalt PG70 ⁽¹⁾			
Service life for 20 years (10 ⁶ ESA5)	<2	>2-5	>5-10	>10-15	>15-30	>30-50	>50-100	>100-150	>150-200
Pavement Thickness (mm)									
AC WC	60 ⁽²⁾	40	40	40	40	40	40	50	40
AC BC	-	65	75	75	60	60	75	80	60
	-	80	80	-	-	-	-	-	-
AC Base ⁽³⁾	-	-	-	100	80	85	100	100	80
	-	-	-	-	80	100	100	100	80
	-	-	-	-	-	-	-	-	90
Aggregate Foundation Layer A Class ⁽⁴⁾	200	200	200	200	200	200	200	200	200
Aggregate Foundation Layer B Class	150	150	150	150	150	150	150	150	150
Selected Coarse Grained Fill or LFA C Class or Cement Stabilization ⁽⁵⁾	-	-	200	200	200	200	200	200	200

(1) Only for AC WC and AC BC

(2) Marshall blows for 2 x 50 blows

(3) For AC Base with planned traffic load more than 30 million ESA5 may not use asphalt PG70

(4) For pavement with more than 2 lanes each direction, the foundation layer thickness of foundation aggregate layer is minimum of 300 mm

(5) Can use coarse-grained fill which has minimum of 30% CBR with PI 6-15 and maximum grain size of 50 mm or LFA C Class or cement stabilization (UCS 10kg/cm²). If these three of the materials or the equipment cannot be granted, this layer will be LFA B Class with the thickness of 200 mm if the price is the same or lower than those three materials.

(Source: Bina Marga 2024)

Table 3.13 Design Chart-3B Adjustment of Selected Coarse-Grained Fill or *LFA* C Class or Cement Stabilization (only for design chart-3A) planned load 20 years > 5 million ESA5

		Thickness (mm)
Subgrade $6 < \text{CBR} < 10$	Selected Coarse Grained Fill or <i>LFA</i> C Class or Cement Stabilization	200
Subgrade $10 \leq \text{CBR} < 30$	Selected Coarse Grained Fill or <i>LFA</i> C Class or Cement Stabilization	150
Subgrade $\text{CBR} \geq 30$	Selected Coarse Grained Fill or <i>LFA</i> C Class or Cement Stabilization	-

(Source: Bina Marga 2024)

Table 3.14 Design Chart-4 Flexible Pavement Design with HRS ¹

Cumulative Axle Load 20 years in Planned Lane (10^6 CESA5)	FF1 < 0,5	$0,5 \leq \text{FF2} \leq 4,0$
Type of surface	HRS or Macadam Penetration	HRS ²
Pavement Structure	Pavement thickness (mm)	
HRS-WC	50	30
HRS-Base	-	35
<i>LFA</i> A Class	150	250
<i>LFA</i> B Class or natural gravel or dis-stabilisation layer with $\text{CBR} > 10\%$ ³	150	150

Note:

¹ Design Chart-4 is an alternative for site which HRS shows the good history of performance and the area that can provide gap graded mix materials

² HRS is not suitable for steep slope and urban area with load more than 2 million ESA5

³ Natural gravel or stabilization materials with $\text{CBR} > 10\%$ can be the most economical choice if the materials are available and competent provider is present.

(Source: Bina Marga 2024)

3.1.5 Road Foundation Design

The important factors that need to be considered in pavement design are traffic, subgrade, and water impacts. Furthermore, in case of pavement that needs to be built on peat soil, expansive soil, and soft soil, the soil characteristics are other important factors since the subgrade analysis may not result in pavement's performance which is hoped for. Therefore, accurate determination of subgrade bearing capacity is an important requirement to obtain the desirable pavement's performance.

Subgrade of the road foundation needs to meet those criteria as follows.

1. Having minimum CBR immersion value;
2. Not sensitive to change in water content;
3. Formed well in accordance to road geometry;
4. Thickness of compaction has to use specified equipment and the compaction result meets requirement; and
5. Able to withstand the traffic load of construction process.

The service life of foundation for new design and widening is 40 years in minimum with the consideration as follows.

1. The pavement foundation is not improved throughout the service life, unless with total reconstruction.
2. The flexible pavement with foundation design below the standard (under design) may need strengthening with additional asphalt layer multiple times throughout its service life so that the life cycle cost is more expensive than the pavement that is well designed.
3. Rigid pavement above the soft soil with the foundation design below the standard (under design) tends to experience the early deformation which in the worst case would probably need the change of concrete pavement construction.

3.2 Flexible Pavement Design with Mechanistic – Empirical Method

The basic from the design procedure of flexible pavement used in Bina Marga 2024 manual is mechanics of material characteristics and mechanics of structural analysis of the pavement. This method is using several inputs such as wheel load, pavement structure, and mechanics of material characteristics, with the output of the pavement structure response to wheel load such as stress, strain, or deflection.

The structural response of the pavement is used to predict the pavement structure performance in permanent deformation and fatigue crack. Since the prediction is based on the material performance in laboratory and the observation in the field, this approach is known as mechanistic – empirical method.

The main advantage of the mechanistic design method is that it allows the analysis of influence in change of design input, such as the change of material and traffic load, fast and rationally. More of the advantages of this method compared to the empirical method is as follows.

1. It can be used analytically to evaluate the change or variation of vehicle load to the pavement performance.
2. The pavement performance with new materials can be evaluated based on the mechanical characteristics of the relevant material mechanics.
3. It can be used to analyse the influence on material characteristics change due to environment and climate toward the pavement performance.
4. It can evaluate the pavement response regarding the pavement damage mode specifically (fatigue crack and permanent deformation).

Generally, pavement structure model that is used in the 2024 Bina Marga manual is multi-layered structure which is linear elastic, isotropic (for bounded material), and anisotropic for unbounded material, CTB layer is assumed in post cracking condition.

For isotropic material, two elastic parameters which are being used is elastic modulus E and Poisson ratio (μ). For cross-anisotropic material, there are 5 (five) elastic parameters needed which are E_v , E_h , μ_{vh} , μ_{hh} , and friction modulus (f). With E_v and E_h each are vertical and horizontal direction modulus. μ_{vh} and μ_{hh} each are

Poisson ratio in vertical due to horizontal. In regards to the practical consideration, Poisson ratio in both of the direction is assumed to be identical.

Non-linear granular material characteristic is approached by dividing the granular layer into several layer with different E modulus.

The procedure used is based on the assumption that 2 (two) critical strain related to the pavement performance are:

1. Vertical compressive strain on the surface layer of the base.
2. Horizontal tensile strain on the bounded lowest layer (asphalt or other bounding material such as cement or lime).

Vertical compressive strain happens on the base layer is used as the design criteria to control the accumulation of permanent deformation. Horizontal tensile strain on the bounded lowest layer is used as a criterion to control the deformation due to fatigue cracking in the considered layer.

Both of the critical strains are the function from the base soil mechanical characteristics and pavement materials, pavement structure (thickness and the characteristic of layer material) and the traffic load. The model which correlates the strain value with the allowed cumulative design load is called the structural performance model (fatigue cracking and permanent deformation) or transfer function.

Even though the mechanistic method and detailed traffic load (from WIM study) is allowing the load analysis due to the actual load spectrum, however with the practical consideration, in 2024 Bina Marga manual the traffic load is stated in equivalent standard axle (ESA). Hence, the critical strains performed are calculated by the standard axle load.

The design procedure based on the multi-layered structural analysis is based on the standard axle load. The location of critical strain on the pavement model and the standard load is illustrated by Figure 3.1 below.

Single Axle Double Tyre

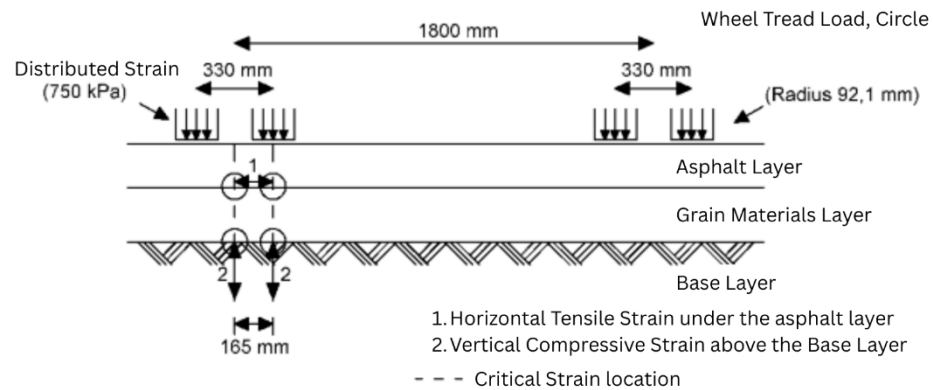


Figure 3.1 Pavement Model on the Mechanistic-Empirical Procedure

(Source: Austroads AGPT02-17)

3.3 Multi-Layered System Concept

Flexible pavements are consisted of layered systems with better materials on the upper side which cannot be constituted by a homogeneous mass, hence, with the modern computation, the theory can be applied to a multilayer system with any number of layers (Huang, 2012). The Figure 3.2 below is the illustration of an n-layer system.

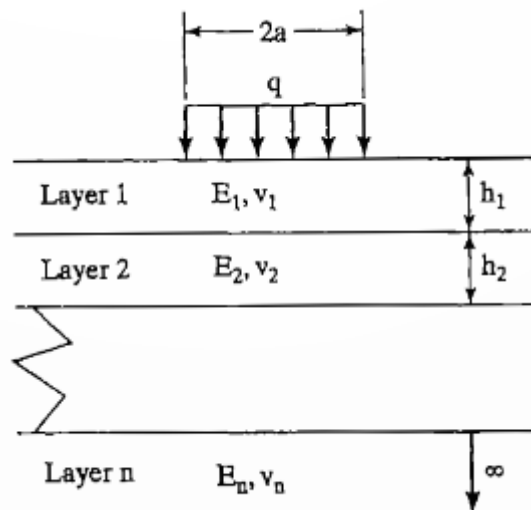


Figure 3.2 An n-layer system subjected to a circular load

(Source: Huang, 2012)

The assumptions to be used in order to compute the structural response in a multi-layered system are as follows.

1. Each layer is homogeneous, isotropic, and linearly elastic with elastic modulus of E and Poisson ratio of ν .
2. The material is considered weightless and infinite in areal extent.
3. Each layer has finite thickness h in contrast to the lowest layer.
4. A uniform pressure of q is applied on the surface over a circular area with radius of a .
5. Continuity conditions are fulfilled at the layer interfaces, as designated by the same vertical stress, shear stress, vertical displacement, and radial displacement.

Based on the Figure 3.2, each layer of the pavement has different thickness and different values of modulus elasticity E and Poisson ratio μ due to the different materials that are being used. The normal stress of σ perpendicularly acts to the surface, meanwhile the shear stress of τ parallelly acts to the surface. Due to the equilibrium of static, the shear stress acting on each surface is the same, hence the shear stress resultant can be considered zero. The strain which occurs is formulated in the Equations 3.1 to 3.3 below.

$$\varepsilon_z = \frac{1}{E} [\sigma_z - \mu(\sigma_r + \sigma_t)] \quad (3.4)$$

$$\varepsilon_r = \frac{1}{E} [\sigma_r - \mu(\sigma_t + \sigma_z)] \quad (3.5)$$

$$\varepsilon_t = \frac{1}{E} [\sigma_t - \mu(\sigma_z + \sigma_r)] \quad (3.6)$$

with:

- ε = strain,
- E = elasticity modulus of each layer,
- μ = Poisson ratio of each layer,
- σ = normal tension
- τ = shear stress

3.4 Pavement Design Analysis with KENPAVE Software

KENPAVE Program is a software specialized in designing pavement developed by Yang H. Huang, Sc. D., P.E., the Professor Emeritus of Civil Engineering in University of Kentucky. The data needed to run the analysis of the pavement structure using KENPAVE are elasticity modulus of E, Poisson ratio (μ) of each layer, wheel load, tyre pressure, and the coordinates where the stress and strain. The program is consisted of four separate sub-programs such as Layerinp, Kenlayer, Slabinp, and Kenslab. The Layerinp and Kenlayer programs are what the author used in this study which is focused on the flexible pavement analysis.

3.4.1 KENPAVE Program

The Figure 3.3 below is the main display menu of the KENPAVE Program.



Figure 3.3 KENPAVE Program Main Display Menu

The steps to analyse pavement design on KENPAVE program are as follows.

1. Determining material properties data for structural modelling which includes pavement thickness data, elasticity modulus (E), and Poisson ratio in each of the pavement layer to be analysed.

The value of the elasticity modulus for several pavement material types can be seen in the below.

Table 3.15 Modulus Characterization of Bounded Materials used to develop Design Chart and for Mechanistic Analysis

Material	Typical Modulus	Poisson ratio
HRS-WC	800 MPa	0,40
HRS-BC	900 MPa	
AC-WC (2 x 75 blows)	1.100 MPa	
AC-WC (2 x 50 blows)	1.000 MPa	
AC BC (2 x 75 blows)	1.200 MPa	
AC-Base (2 x 75 blows)	1.500 MPa	
AC-WC PG70 (2 x 75 blows)	1.300 MPa	
AC-BC PG70 (2 x 75 blows)	1.400 MPa	
CTB	3.000 MPa (pre cracking)	0,20
CTB	500 MPa (post cracking)	0,20 (pristine) 0,35 (cracked)
Base layer (adjustable to seasons)	10 x CBR (MPa)	0,45 (cohesive soil)
		0,35 (non-cohesive soil)

(Source: Bina Marga 2024)

Poisson ratio is the ratio of horizontal strain (lateral strain) to the vertical strain (axial strain) due to parallel axis load and axial strain. The value of Poisson ratio based on the material type can be seen in Table 3.16 below.

Table 3.16 Poisson Ratio Value

Material	v Value	V Typical
Hot mix asphalt	0,30 – 0,40	0,35
Portland cement concrete	0,15 – 0,20	0,15
Untreated granular material	0,30 – 0,40	0,35
Cement treated granular material	0,10 – 0,20	0,15
Cement treated fine grained material	0,15 – 0,35	0,25
Lime stabilized material	0,10 – 0,25	0,20
Lime fly ash mixture	0,10 – 0,15	0,15
Loose sand / silty sand	0,20 – 0,40	0,30
Dense sand	0,30 – 0,45	0,35
Fine grained soil	0,30 – 0,50	0,40
Saturated soft clay	0,40 – 0,40	0,45

(Source: Huang, 2012)

2. Analysing traffic data which is consisted from the pavement analysis period, calculating Equivalent Single Axle Load (ESAL), and determining the axis wheel load detail of vehicles.
3. Executing the structural modelling of the pavement with KENPAVE program by subprogram KENLAYER by using viscoelastic and elastic approaches.
4. Determining the output result from KENLAYER program to investigate the stress and strain responses resulted from the traffic load from both of the approaches.

5. Analysing the traffic load repetition from KENPAVE program and analysing the service life from two approaches.

3.4.2 KENLAYER Program

The analysis of flexible pavement is using KENLAYER program as a part of KENPAVE Program. The KENLAYER program is used to determine the pavement flexural damage ratio using stress models. Distressed model is the deformation and cracking which is used to predict the pavement's life by the assumption of pavement configuration.

The KENLAYER program requires the data input through the Layerinp menu in the software as shown in Figure 3.4. Layerinp provides 10 menus to be input with the existing data.

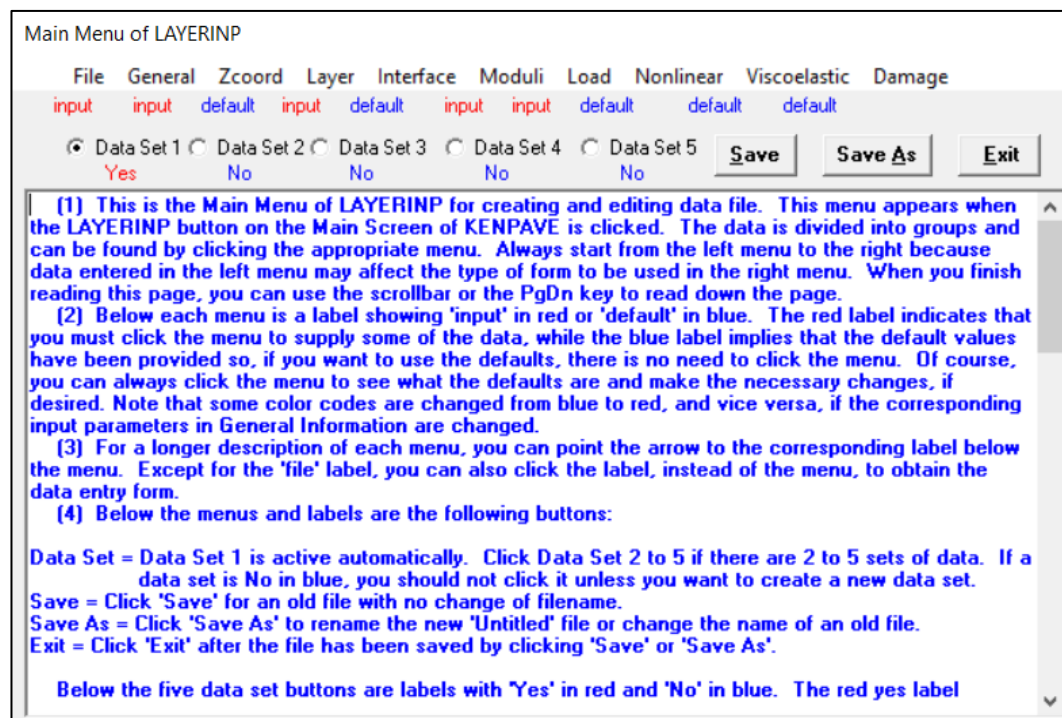


Figure 3.4 Layerinp Main Menu Display

The pavement structure data such as pavement thickness, elasticity modulus, Poisson ratio, and load conditions are what need to be input to the KENLAYER program. The pavement thickness is determined using the regulation of 2024 Bina Marga. The value of the elasticity modulus can be determined by Table 3.15, and the value of Poisson ratio is determined by Table 3.16.

3.5 Pavement Damage Analysis

Pavement damage is mostly caused by vehicle loads. In the calculations by the KENPAVE program, the stress and strain values of the flexible pavement will be generated then used to predict damages to the pavement. The road pavement damage analysis that will be discussed are fatigue cracking, rutting, and permanent deformation.

3.5.1 Fatigue Cracking

The fatigue crack values on flexible pavement which determine the number of load repetitions based on the tensile strain under the surface layer can be formulated as follows.

$$N_f = 0,0796(\varepsilon_t)^{-3,921}|E|^{-0,854} \quad (3.7)$$

with:

- N_f = Number of allowable load repetitions to control fatigue cracking (ESAL),
- ε_t = Tensile strain in the critical analysis location which is calculated based on the structural model response or tensile strain at the lower of the surface layer (cm),
- E = Elasticity modulus on the surface layer (KPa).

3.5.2 Rutting

The rutting values on flexible pavement which determine the number of load repetitions based on the compressive strain under the subbase layer can be formulated as follows.

$$N_r = 1,365 \times 10^{-9} \times \varepsilon_c^{-4,47} \quad (3.8)$$

with:

- N_r = Number of allowable load repetitions to control rutting (ESAL),

ε_t = Vertical tensile strain on the base layer (cm).

3.5.3 Permanent Deformation

The permanent deformation on flexible pavement which determine the number of load repetitions can be formulated as follows.

$$N_d = 1,365 \times 10 \times \varepsilon_c^{-4,47} \quad (3.9)$$

Nd = Number of allowable load repetitions to control deformation (ESAL),

ε_t = Vertical tensile strain on the lower of the foundation layer (cm).

CHAPTER 4

RESEARCH METHODS

4.1 Research Method

This research relied on the secondary data of average daily traffic load data on the Peureulak-Bts road KM 7+750 – 16+500 in Langsa City, East Aceh. After all the data is collected, the alternative pavement designs are then determined by referring to the 2024 Highway Pavement Design Manual released by *Direktorat Bina Marga*, also known as 2024 Bina Marga, using the formulation determined to calculate the cumulative equivalent single axle load (CESAL). The service life is determined to be 20 years. After the alternative pavement designs are obtained, the damage analysis is then computed by the KENPAVE program to pre-determine whether there is a structural failure on the alternative pavement design which happens during the service life so the ideal alternative design of the pavement is obtained for further design purpose and reference.

4.2 Research Data

The research data is the secondary data obtained from Commitment Maker Office (PPK) of Working Unit of Planning and Inspection of National Road (*Satker P2JN*) of Aceh Province which is the average daily traffic (*LHR, Lalulintas Harian Rata-rata*) on Peureulak – Bts road KM 7+750 – 16+500 in Langsa City, East Aceh.

4.3 Research Location

The research location is Peureulak – Bts road KM 7+750 – 16+500 in Langsa City, East Aceh. The detailed location on the digital map can be seen in Figure 4.1 below.

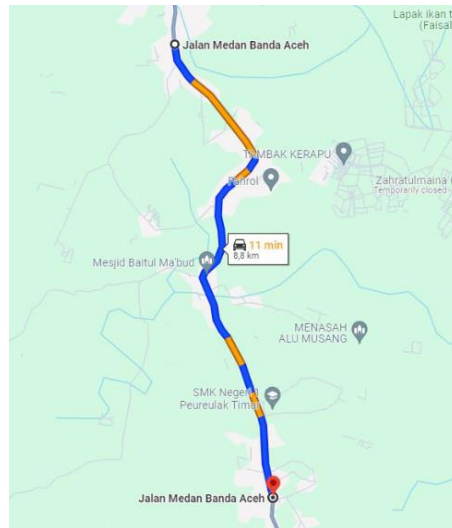


Figure 4.1 Research Location
(Source: Google Maps 2025)

4.4 Research Stages

The research stages explained with the flowchart for easier understanding can be seen in the Figure 4.2 below.

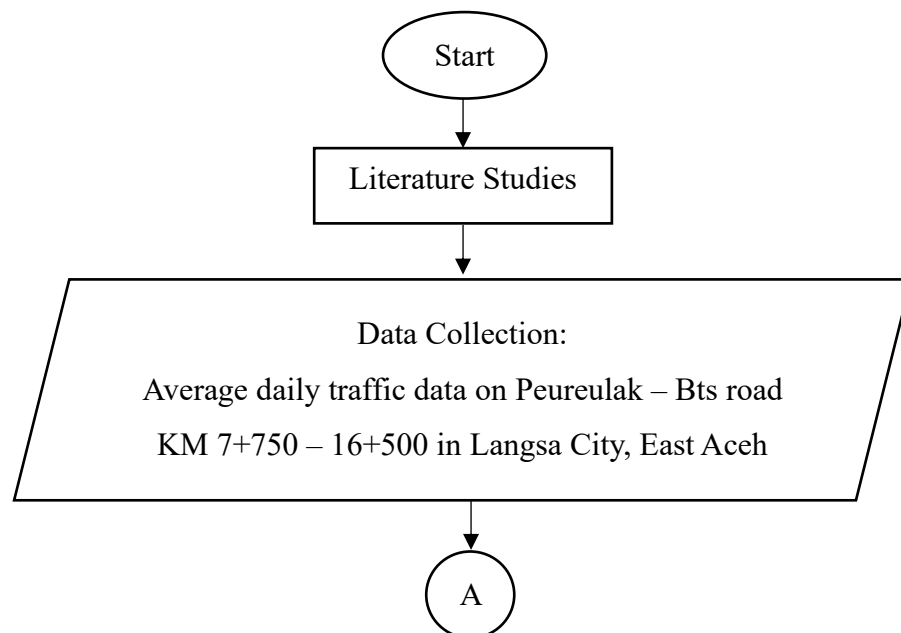
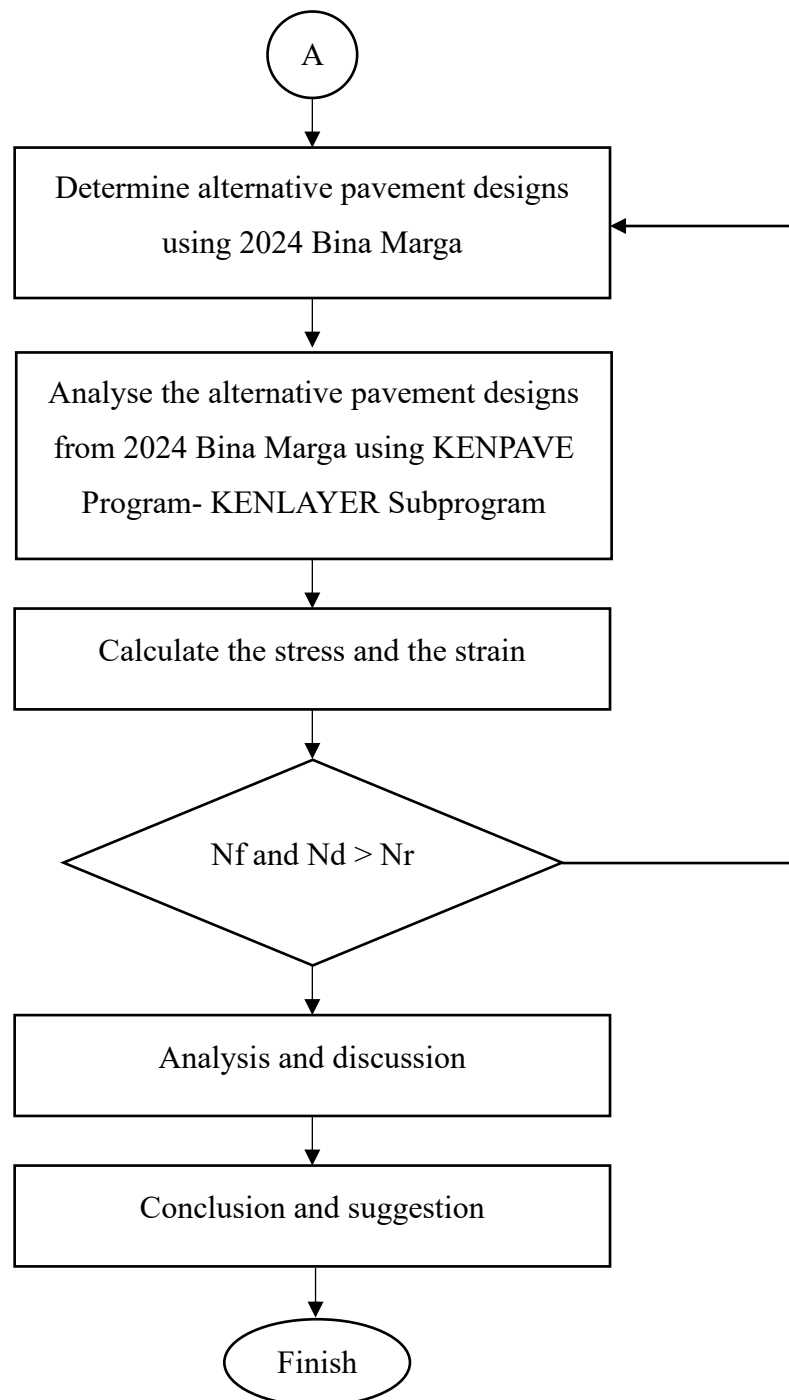


Figure 4.2 Research Flowchart



Continuation of Figure 4.2 Research Flowchart

4.4.1 Determining Alternative Pavement Designs by 2024 Bina Marga Methods

The determination of alternative pavement designs using 2024 Bina Marga methods explained with flowchart for better understanding can be seen in below.

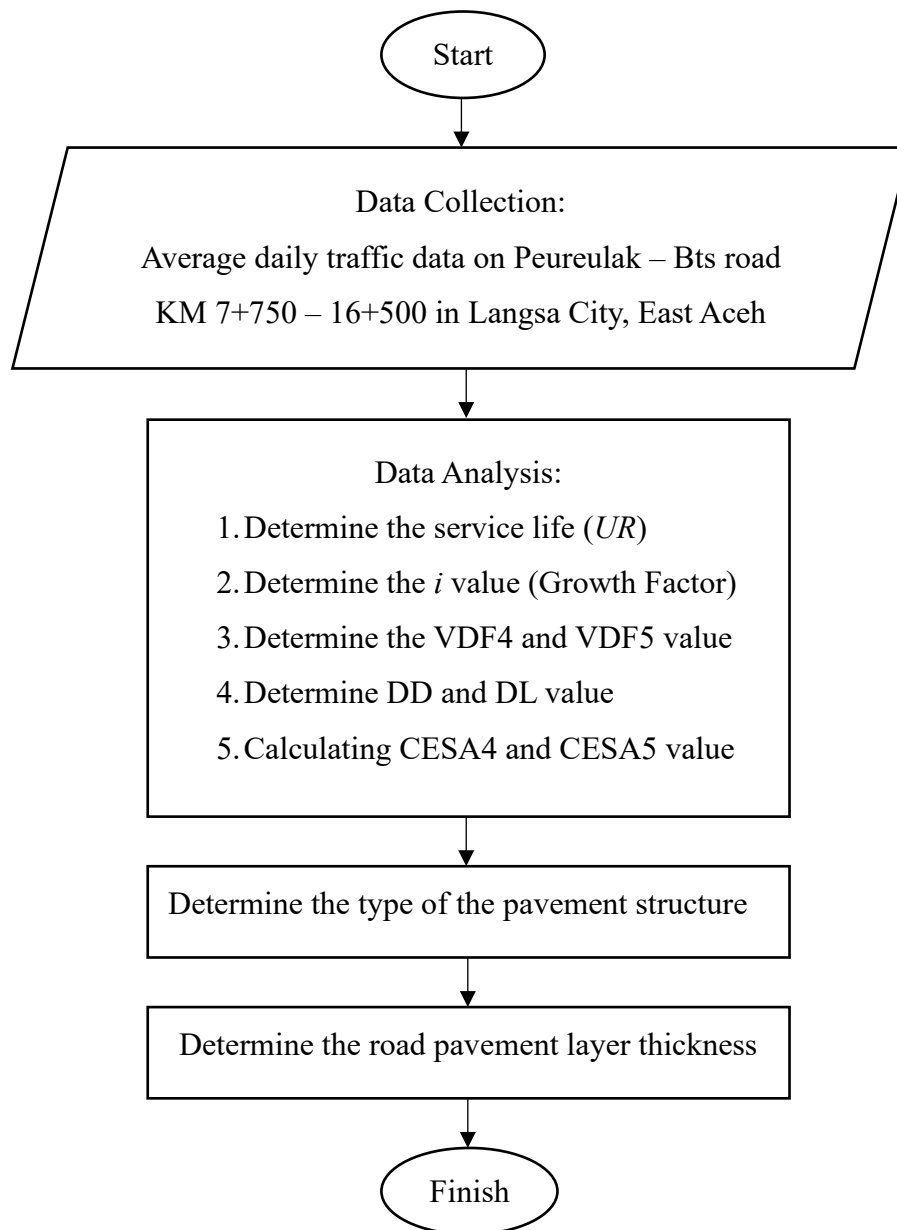


Figure 4.3 Flexible Pavement Design Procedure using 2024 Bina Marga

4.4.2 KENPAVE Methods

To analyse the alternative pavement designs structure with KENPAVE program, the following steps in the flow chart for better understanding in below should be done.

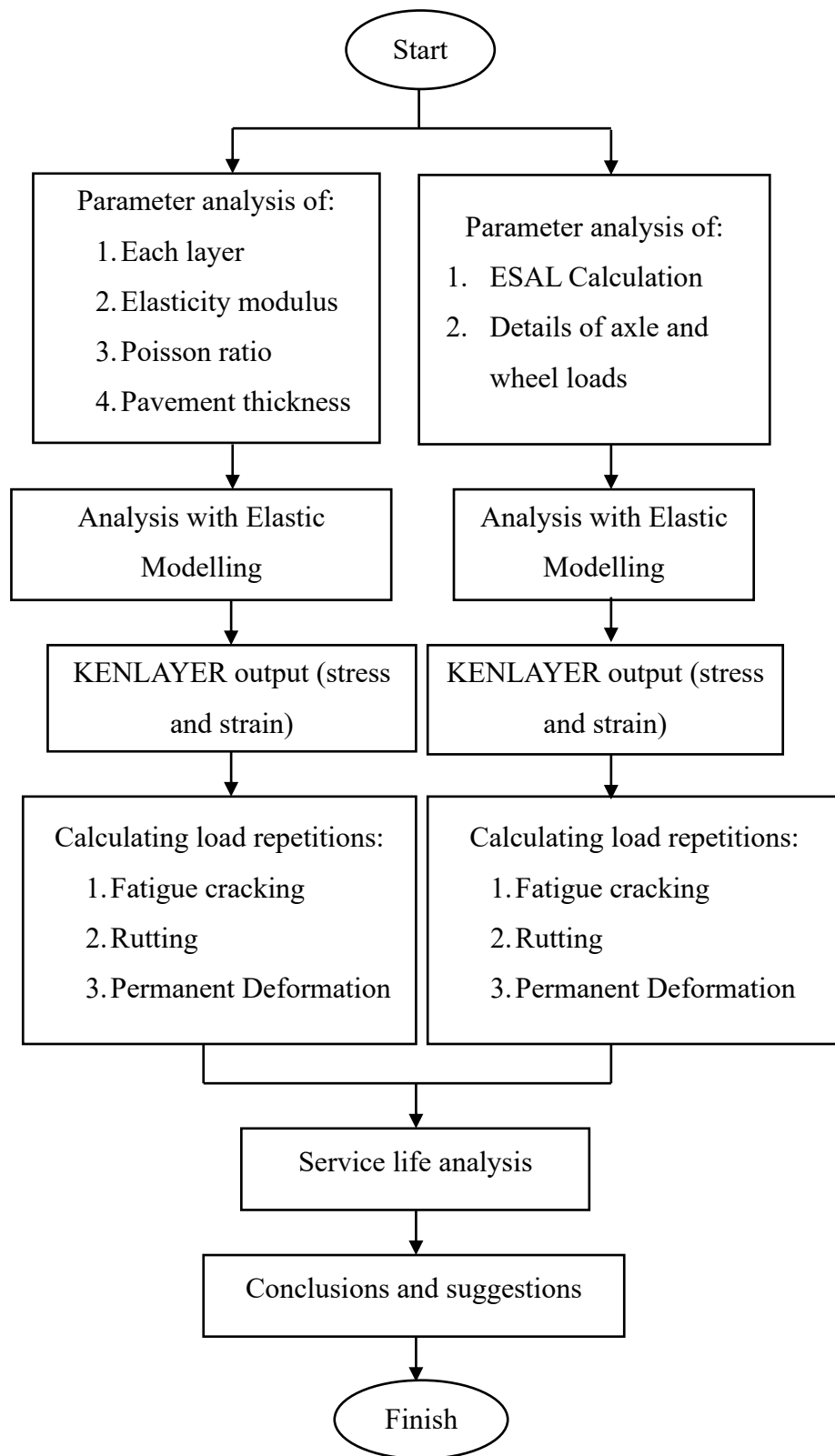


Figure 4.4 KENPAVE Method Flowchart

CHAPTER 5

ANALYSIS AND DISCUSSION

5.1 Research Data

The research data acquired to determine the alternative pavement designs to the Peureulak – Bts road KM 7+750 – 16+500 in Langsa City, East Aceh is the secondary data of average daily traffic. The data was obtained from a survey in April 2023 by the Commitment Maker Office (PPK) of Working Unit of Planning and Inspection of National Road (*Satker P2JN*) of Aceh Province.

The average daily traffic data of Peureulak – Bts road in Langsa City, East Aceh by the Commitment Maker Office (PPK) of Working Unit of Planning and Inspection of National Road (*Satker P2JN*) of Aceh Province is in the following Table 5.1 below.

Table 5.1 Average Daily Traffic (*LHR*) on Peureulak – Bts road

No.	Group of Vehicles	LHR 2023 (vehicle/day)
1	1	15.792
2	2	296
3	3	5.686
4	4	1.418
5	5A	30
6	5B	102
7	6A	84
8	6B	1.314
9	7A	676
10	7B	0
11	7C	68
12	8	8

5.2 2024 Bina Marga Methods

The 2024 Bina Marga methods to determine the alternative pavement designs to the Peureulak – Bts road in Langsa City, East Aceh is as follows.

5.2.1 Traffic Load Analysis

The steps to analyse the traffic load of the Peureulak – Bts road in Langsa City, East Aceh according to the 2024 Bina Marga methods are described in the following steps.

1. Traffic Growth Factor

Traffic growth rate (i) from the cumulative traffic growth is the landmark of the traffic growth calculation during the service life. It is shown in Table 3.3 that Sumatera province has traffic growth rate of 4,83% with the service life (UR) of 20 years. According to 2024 Bina Marga, it is assumed that the start of the normal load period MST 12 ton is in the year of 2028. It is known that the traffic load survey was conducted in April 2023 and the road is assumed to start serving traffic in 2026, which can be formulated as follows.

$$\begin{aligned} R_{(2026-2028)} &= \frac{(1+(0,01 \times i)^{UR}-1}{0,01 \times i} \\ &= \frac{(1+(0,01 \times 0,0483)^2-1}{0,01 \times 0,0483} \\ &= 2,000483 \end{aligned}$$

The traffic growth factor during the normal load period starting in 2028 is as follows.

$$\begin{aligned} R_{(2028-2046)} &= \frac{(1+(0,01 \times i)^{UR}-1}{0,01 \times i} \\ &= \frac{(1+(0,01 \times 0,0483)^{18}-1}{0,01 \times 0,0483} \\ &= 18,074 \end{aligned}$$

2. Traffic in the Planned Lanes

The traffic volume should be distributed in the specified direction of a lane for the design objective. The traffic load in the planned lane is expressed in the equivalent standard axle (ESA) by considering the direction distribution factor (DD) and lane distribution factor of the commercial vehicles (DL). Direction distribution factor (DD) is usually determined for each direction of 0,50, which can also range around 0,30 – 0,70 and for the lane distribution factor (DL), the value determined will depend on the number of the lanes in specified direction. Meanwhile for the road with two lanes as in the Peureulak – Bts road in Langsa City, East Aceh, the lane distribution factor (DL) is determined to be 1,0 (Table 3.4).

3. Vehicle Damage Factor

According to the VDF of each commercial vehicle type which is shown in Table 3.6, hence the VDF4 and VDF5 values of each vehicle type are shown in the Table 5.2 below.

Table 5.2 The VDF Value of Each Vehicle Type

Vehicle Type	Group	Condition			
		VDF4		VDF5	
		Factual	Normal	Factual	Normal
Big buses	5B	1,2	1,2	1,3	1,3
2-axle light truck	6A	0,5	0,5	0,4	0,4
2-axle medium truck	6B	1,6	0,4	2,2	0,4
3-axle heavy truck	7A1	10,1	3	17,2	3,4
4-axle heavy truck	7C1	8,2	5,7	11,9	7,2

VDF value used depends on the normal load period of heaviest axle load (MST, *Muatan Sumbu Terberat*). VDF_{factual} is used in the situation before the normal

load period and VDF_{normal} is used in the situation after the normal load begins to operate. VDF_4 is used to compute the value of CESA4 which was the standard being used to determine the pavement types in the previous version of 2017 Bina Marga, while VDF_5 is used to compute the value of CESA5 to determine the type and the thickness of the pavement needed in the alternative pavement designs.

4. Cumulative Equivalent Single Axle Load (CESAL)

Cumulative Equivalent Single Axle Load (CESAL) is the cumulative traffic axle load in the designed lanes during 20 years of service life which is formulated as follows.

a. CESA5

Group of 5B Vehicle

$$\begin{aligned} ESA_{factual} &= (ADT_{2026} \times VDF_{factual}) \times 365 \times DD \times DL \times R \\ &= (ADT_{2023} \times (1+i/100)^3 \times VDF) \times 365 \times DD \times DL \times R_{2026} \\ &= (102 \times (1+4,83/100)^3 \times 1,3) \times 365 \times 0,5 \times 1,0 \times 2,000483 \\ &= 55.769,662 \end{aligned}$$

$$\begin{aligned} ESA_{normal} &= (ADT_{2026} \times VDF_{normal}) \times 365 \times DD \times DL \times R \\ &= (ADT_{2023} \times (1+i/100)^3 \times VDF) \times 365 \times DD \times DL \times R_{2026} \\ &= (102 \times (1+4,83/100)^3 \times 1,3) \times 365 \times 0,5 \times 1,0 \times 18,074 \\ &= 553.720,695 \end{aligned}$$

The complete calculation of CESA5 for each vehicle type can be seen in below.

Table 5.3 Recapitulation of Traffic Load Analysis

Vehicle Type	ADT 2023 (2 way)	ADT 2024	ADT 2025	ADT 2026	ADT 2028	VDF5 Factual	VDF5 Normal	DD	DL	R (i=4,83%)		CESA5	
										(2 years)	(18 years)	Factual	Normal
										2026-2028	2028-2046	2026-2028	2028-2046
(1)	(2)	(3)	(4)	(5)	(6)	(9)	(10)	(11)	(12)	(13)	(14)	(17)	(18)
1-4	23192	24312	25486	26717	29361	-	-	0.5	1	2.000483	18.07408971	0	0
5A	30	31	33	35	38	-	-	0.5	1	2.000483	18.07408971	0	0
5B	102	107	112	118	129	1.3	1.3	0.5	1	2.000483	18.07408971	55769.66238	553720.6951
6A	84	88	92	97	106	0.4	0.4	0.5	1	2.000483	18.07408971	14131.67916	140309.3164
6B	1314	1377	1444	1514	1664	2.2	0.4	0.5	1	2.000483	18.07408971	1215829.11	2194838.592
7A1	676	709	743	779	856	17.2	3.4	0.5	1	2.000483	18.07408971	4890233.925	9597825.381
7C1	68	71	75	78	86	11.9	7.2	0.5	1	2.000483	18.07408971	340337.9397	2044507.182
											ESA Total	6.516.302,316	14.531.201,17
											CESA5	21.047.503,48	

5.2.2 Determining the Pavement Types and Thickness

CESA value, which has been calculated previously, will influence the type of the pavement. According to the calculation of CESA5 value which resulted 21.047.503,48, referring to Table 3.2, the type of pavement obtained is AC with CTB or AC with aggregate foundation layer.

The determination of the pavement thickness can be referred to the Table 3.8, Table 3.9, Table 3.10, Table 3.11, Table 3.12, and Table 3.13. Since the CESA5 value of 21.047.503,48 is obtained, the axis vehicle group are in the category of F(1) 4, F(2) 3, F(3) 3, F(4)3, and FFF(1) 5 which are detailed in the following Table 5.4.

Table 5.4 Options of Flexible Pavement Design Thickness

No	Foundation Type	Layer	Thickness (mm)
1	150mm CTB	AC-WC	40
		AC-BC	65
		CTB	150
		LFA Class B	150
		Selected Coarse-grained Fill/LFA Class C/Cement Stabilization	200
2	200mm CTB	AC WC	50
		AC BC	80
		CTB	200
		LFA Class B	150
		Selected Coarse-grained Fill/LFA Class C/Cement Stabilization	200

Continuation of Table 5.4 Options of Flexible Pavement Design Thickness

No	Foundation Type	Layer	Thickness (mm)
3	250mm CTB	AC-WC	50
		AC-BC	80
		CTB	250
		LFA Class B	150
		Selected Coarse-grained Fill/LFA Class C/Cement Stabilization	200

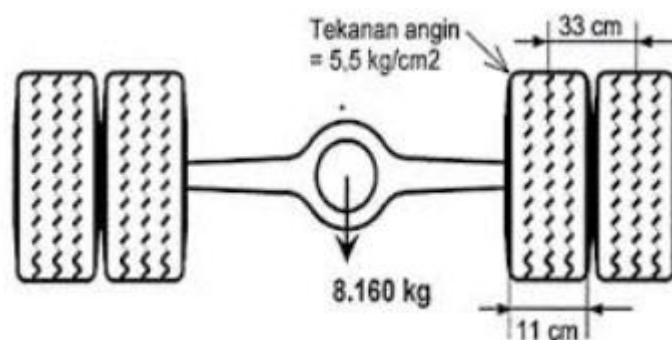
5.3 Alternative Flexible Pavement Design Using Elastic Modelling on KENPAVE Program

The alternative flexible pavement designs obtained by 2024 Bina Marga methods can be directly analysed with KENPAVE program for its stress and strain responses to determine the amount of damage occurred in the service life of the pavement.

5.3.1 Data Analysis

1. Wheel axle load details

The wheel axis detail data used is referring to the wheel axis detail data set in Indonesia according to Sukirman (1992) in the Figure 5.1 below.

**Figure 5.1 Equivalent Standard Axis**

(Source: Sukirman, 1992)

- a. The standard axle load of the vehicle is 18.000 pounds or 8,160 ton.
- b. The wheel pressure for one tire is 0,55 kg/cm² or 0,55 MPa.
- c. The radius of the contact area is 11 cm.
- d. The distance between each of double-axle is 33 cm.

2. Parameters of Each Pavement Layer

The analysis uses linear elastic material, hence modulus and Poisson ratio parameters are used in this calculation as in Table 5.5 below.

Table 5.5 Parameter of Each Pavement Layer

AC-WC	Elasticity Modulus (E)	1.100 MPa
	Poisson Ratio	0,4
AC-BC	Elastic Modulus (E)	1.200 MPa
	Poisson Ratio	0,4
AC-Base (CTB)	Elastic Modulus (E)	500 MPa
	Poisson Ratio	0,35
Base Course	Elastic Modulus (E)	250 MPa
	Poisson Ratio	0,35
Soil Base	Elastic Modulus (E)	143,36 MPa
	Poisson Ratio	0,45

5.3.2 KENPAVE Program Input

1. Layerinp Menu Input

There are several options provided to fill the required data in Layerinp menu based on the properties of flexible pavement materials being analyzed. Layerinp menu can be seen in below.

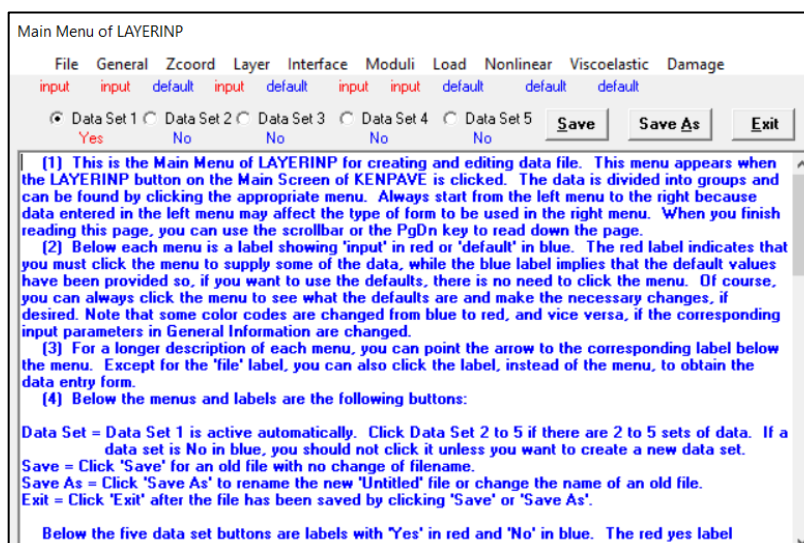


Figure 5.2 Layerinp Menu Layout

2. General

In the General menu, fill in the values with the data as shown in Table 5.6 below.

Table 5.6 General Menu Data Input

Parameter	Value	Description
Title	Design 3.1	Title of the analysis file
MATL	1	Linear Elastic Material selection
NDAMA	0	No damage analysis used
NPY	1	Default option
NLG	1	Default option
DEL	0,001	Accuracy standard
NL	5	The pavement layers numbers to be analysed
NZ	5	The location of Z coordinates

Continuation of Table 5.6 General Menu Data Input

Parameter	Value	Description
ICL	80	Default option
NSDT	9	To run the analysis with the output of vertical displacement, four stress and four strains
NBONT	1	All interfaces are bonded
NLBT	1	Default options
NLTC	1	Default option
NUNIT	1	Use SI Unit

The General menu layout can be seen in the Figure 5.3 below.

General Information of LAYERINP for Set No. 1

TITLE 31

Type of material (1=linear, 2=nonlinear, 3=viscoelastic, 4=combined)	(MATL)	1
Damage analysis (0=no, 1=yes with summary only, 2=yes with detailed printout)	(NDAMA)	0
Number of periods per year	(NPY)	1
Number of load groups	(NLG)	1
Tolerance for numerical integration	(DEL)	0
Number of layers	(NL)	5
Number of Z coordinates for analysis	(NZ)	5
Maximum cycles of numerical integration	(ICL)	80
Type of responses (1=displacements only, 5=plus stresses, 9=plus strains)	(NSTD)	9
All layer interfaces bonded (1=yes, 0=if some are frictionless)	(NBOND)	1
Number of layers for bottom tension	(NLBT)	1
Number of layers for top compression	(NLTC)	1
System of units (0=English, 1=SI)	(NUNIT)	1

OK

(1) This form appears when the 'General' on the Main Menu of LAYERINP is clicked. You can override any of the default values by typing in a new value. You can use the Tab key to move the cursor from one textbox to the next or just click on the textbox before typing. The use of click has the advantage that you don't have to delete the default before typing in the data you want. If you want to read the remaining text, you can use the scrollbar. You can also use the PgDn key after clicking this textbox to make it active.

(2) TITLE (title of run): Any title or comment can be typed on one line. The title should not be longer than 68 characters including spaces. If you make a mistake in typing, use the Del key to erase any typographical errors. When the total length reaches 68, no additional characters can be added. No comma should be used in TITLE. Use colon or semicolon instead.

(3) MATL (types of material): 1 when all layers are linear elastic, 2 when some layers are nonlinear

Figure 5.3 General Data Input Layout

3. Zcord

The Zcord data to be input is the depth of the point where the damage will be repaired. In the analysis, the depth data is the depth of the pavement surface, flexible pavement base, foundation layer surface, foundation layer base, and subgrade as shown in Table 5.7 below.

Table 5.7 Zcord Input Data

No	Depth (cm)	Description
1	0	Pavement surface
2	10,495	Pavement base
3	10,505	Foundation layer surface
4	40,495	Base layer foundation
5	40,505	Subgrade

The Zcord menu layout can be seen in the Figure 5.4 below.

Z Coordinates of Response Points for Data Set No. 1

Unit cm

Point No.	ZC
1	0
2	10.495
3	10.505
4	40.495
5	40.505

(1) This form appears when the 'Zcord' menu on the Main Menu of LAYERINP is clicked. The number of Z coordinates on this form is equal to NZ, as specified in the 'General' menu. This form is different from the one used for General Information in that a dotted rectangle, instead of the cursor, is used to indicate the active cell. If the dotted rectangle is not the location for input, you can use the arrow key to move the dotted rectangle to the cell you want to input, or more conveniently by clicking the cell you want. After you type in the data, the dotted rectangle will be changed into a three dimensional box and you must press the Enter key to make it effective. You can also use the up and down arrow keys to make the entry effective. You should not click the other cell before pressing the Enter key, otherwise the data you have typed will move to the cell you click.

(2) ZC (vertical distance, or z coordinate, of each response point): When the point is located exactly at the interface between two layers, the results are at the bottom of upper layer. If the results at the top of lower layer are desired, a slightly larger z coordinate, say 0.0001 larger, should be used.

(3) After typing in the data in the first cell, move to the next cell by pressing the Enter or arrow down key.

Use <Ctrl>- to delete a line, <Ctrl>-<Ins> to insert a line, and to clear a cell.

OK

Figure 5.4 Zcord Input Data Display

4. Layer

The pavement thickness data will be input in Layer menu with the Poisson ratio value of the pavement to be analysed. The Poisson ratio value is determined based on Table 5.5 according to 2024 Bina Marga. The data input to the Layer menu is as seen in Table 5.8 below.

Table 5.8 Layer Input Data

No Layer	Thickness (cm)	Poisson Ratio	Description
1	4	0,4	AC-WC
2	6,5	0,4	AC-BC
3	15	0,35	CTB
4	15	0,35	LFA Class B
5	∞	0,45	Subgrade

The Layer thickness menu layout can be seen in the Figure 5.5 below.

Layer Thickness, Poisson's Ratio and Unit Weight for Data Set No. 1

After typing the value in a cell, be sure to press the Enter key to make it effective.

Unit cm kN/m³

Layer No.	TH	PR
1	4	.4
2	6.5	.4
3	15	.35
4	15	.35
5	XXXXXXXXXX	.45

Use <Ctrl>- to delete a line, <Ctrl>-<Ins> to insert a line, and to clear a cell.

(1) This form appears when the 'Layer' menu on the Main Menu of LAYERINP is clicked. The number of layers on this form is equal to NL, as specified in the 'General' menu. This form is different from the one used for General Information in that a dotted rectangle, instead of the cursor, is used to indicate the active cell. If the dotted rectangle is not the location for input, you can use the arrow key to move the dotted rectangle to the cell you want to input, or more conveniently by clicking the cell you want. After you type in the data, the dotted rectangle will be changed into a three dimensional box and you must press the Enter key to make it effective. You can also use the up and down arrow keys to make the entry effective. Note that the dotted rectangle is now in the upper left cell, so you can type in the data right away. If you want to read the remaining text and use the PgDn key, instead of the scrollbar, you

OK

Figure 5.5 Layer Input Data Display

5. Moduli

The data required for the Moduli menu is the Elasticity modulus value of each pavement layer. The Elasticity modulus value according to the 2024 Bina Marga as also shown in Table 5.5 can also be seen in Table 5.9 below.

Table 5.9 Moduli Input Data

No	Elasticity Modulus (kPa)
1	1.100.000
2	1.200.000
3	500.000
4	250.000
5	143.360

The Layer Moduli menu layout can be seen in Figure 5.6 below.

Unit kPa

Layer No.	E
1	1100000
2	1200000
3	500000
4	250000
5	143360

(1) This form appears when the period button on the Layer Modulus of Each Period is clicked. The number of layers on this form is equal to NL, as specified in the 'General' menu.

(2) E (elastic modulus of each layer): Use as the assumed modulus for the first iteration when the layer is nonlinear. If more convenient, you can enter the modulus in exponential form such as 1.234E5. Assign 0 or any value for viscoelastic layer.

(3) After typing the data in the first cell, move to the next cell by pressing the Enter or arrow down key. After the last cell is filled, be sure to click the Enter key.

(4) You can delete a line, or one layer, by first clicking anywhere on the line to make it active and then press the <Ctrl>- keys. The NL in the 'general' menu will be reduced automatically by 1.

(5) You can add a new line, or one more layer, above any given line by first clicking the cell in the given line to make it active and then press the <Ctrl>-<Ins>. A blank line will appear for you to enter the necessary data. The NL in the 'General' menu will increase automatically by 1. If you want to add a line after the last line, you can change NL in the 'General' menu by adding 1 and a blank line will appear as the last line. Remember that always use the <Ctrl>-<Ins>

Use <Ctrl>- to delete a line, <Ctrl>-<Ins> to insert a line, and to clear a cell.

Figure 5.6 Moduli Input Data Menu Display

6. Load

The data of the dimensions of the vehicle axle is needed to be input in the Load menu such as the tire pressure and tire distance on dual wheels. The data input is based on the Figure 5.1 which is the load condition by the data used in Indonesia. The data input is as follows.

- The standard axle load (P) of the vehicle is 8,16 tons
- Wheel pressure (q) for one tire is 550 kPa
- The distance between each double wheel axle is 33 cm

- d. The distance between each double wheel axle is 33 cm
- e. The radius of the contact area (a) is 11 cm

The data above will be input in the Load menu which can be seen in the following Table 5.10.

Table 5.10 Load Input Data

Parameter	Value	Description
LOAD	1	1 for single axle with dual tires
CR	11	Contact radius of circular loaded areas
YW	33	Centre of the spacing between two dual wheels along the y-axis
XW	0	Centre of the spacing between two axles along the x-axis
NR or NPT	3	Number of points in x and y coordinates to be analysed under multiple wheels

The Load Input Data menu display can be seen in the Figure 5.7 below.

Load Information for Data Set No. 1

Double click anywhere on a line to get auxiliary form for NR or NPT.

Unit		cm	kPa	cm	cm	
Load Group No	LOAD	CR	CP	YW	XW	NR or NPT
1	1	11	550	33	0	3

Use <Ctrl>- to delete a line, <Ctrl>-<Ins> to insert a line, and to clear a cell.

(1) This form appears when the 'Load' menu on the Main Menu of LAYERINP is clicked. The number of lines, or load groups, is equal to NLG, as specified in the 'General' menu. Please refer to Figure 3.8 for wheel and axle arrangements.
 (2) LOAD (type of loading): Assign 0 for single axle with single tire, 1 for single axle with dual tires, 2 for tandem axles, and 3 for tridem axles.
 (3) CR (contact radius of circular loaded area).
 (4) CP (contact pressure on circular loaded area).
 (5) YW (center to center spacing between two dual wheels along the y axis): Assign 0 if there is only one wheel or LOAD = 0.
 (6) XW (center to center spacing between two axles along the x axis): Assign 0 if only one axle exists, i.e. LOAD = 0 or 1.
 (7) NR (number of radial coordinates to be analyzed under a single wheel, maximum 25): A single

OK

Figure 5.7 Load Input Data Menu Display

- f. The NPT value is the coordinate value under review which is 3, with the X and Y coordinates can be seen in Table 5.11 below.

Table 5.11 NPT Coordinate

X (cm)	Y (cm)
0	0
0	10
0	16,5

The NPT Coordinate Input Data menu layout can be seen in the Figure 5.8 below.

X and Y Coordinates of Response Points for Load Group No. 1 and Data Set No. 1

Unit	XPT	YPT
cm	0	0
cm	0	10
cm	0	16.5

(1) This auxiliary form appears automatically when NPT of a given load is typed on the main form. If NPT was specified previously, you can also enter this auxiliary form by double clicking the main form anywhere on the given load group, instead of retyping NPT to enter this auxiliary form.
 (2) XPT (x coordinates of points to be analyzed).
 (3) YPT (y coordinates of points to be analyzed).
 (4) After typing the data in a cell, be sure to press the Enter key to make it effective.
 (5) You can delete a line, or one of the points, by first clicking anywhere on the line to make it active and then press the <Ctrl>- keys. The NPT in the main form will be reduced automatically by 1.
 (6) You can add a new line, or one more point, above any given line by first clicking the cell in the given line to make it active and then press the <Ctrl>-<Ins>. A blank line will appear for you to enter the necessary data. The NPT in the main form will increase automatically by 1. If you want to add a line after the last line, you can change NPT in the main form by adding 1 and a blank line will appear as the last line. Remember that always use the <Ctrl>-<Ins> keys to add a line unless the line to be added is the last line. By so doing, you don't have to retype any of the existing lines.
 (7) After completing this form, click OK to return to the

Use <Ctrl>- to delete a line, <Ctrl>-<Ins> to insert a line, and to clear a cell.

OK

Figure 5.8 NPT Coordinate Input Data Menu Display

5.3.3 Result of the Analysis

The result of the KENPAVE program analysis is stress and strain values which occur at the review point of the flexible pavement layer. The recapitulation of the analysis results can be seen in Table 5.12 below.

Table 5.12 Stress and Strain Value for Liner Elastic Modelling for Alternative Pavement Design 1

Load Point (X)	Horizontal P Strain	Vertical Strain	Vertical Strain
	At point 10,495 cm	At point 10,495 cm	At point 40,505 cm
1	$1,965 \times 10^{-4}$	$3,453 \times 10^{-4}$	$2,341 \times 10^{-4}$
2	$1,774 \times 10^{-4}$	$1,877 \times 10^{-4}$	$2,533 \times 10^{-4}$
3	$1,575 \times 10^{-4}$	$8,016 \times 10^{-5}$	$2,561 \times 10^{-4}$
Maximum Value	$1,965 \times 10^{-4}$	$3,453 \times 10^{-4}$	$2,561 \times 10^{-4}$

For the data analysis, the horizontal principal strain value under the surface layer is $1,930 \times 10^{-4}$ which is used to identify the type of fatigue cracking, meanwhile for the vertical strain which is used to identify the type of rutting and permanent deformation is 0,000353 and 0,0002561.

5.3.4 Axle Load Control

The control of the number of the axle loads is conducted by computing the values of fatigue cracking, rutting and permanent deformation, which can be calculated as follows.

1. Fatigue cracking calculation

$$N_f = 0,0976(\varepsilon_t)^{-3,921}|E|^{-0,854}$$

$$N_f = 0,0976(1,965 \times 10^{-4})^{-3,921}|500000|^{-0,854}$$

$$N_f = 369.588.208 \text{ ESAL}$$

2. Rutting calculation

$$N_r = 1,365 \times 10^{-9}(\varepsilon_c)^{-4,47}$$

$$N_r = 1,365 \times 10^{-9}(3,453 \times 10^{-4})^{-4,47}$$

$$N_r = 4.068.121,79 \text{ ESAL}$$

3. Permanent deformation calculation

$$N_d = 1,365 \times 10^{-9}(\varepsilon_c)^{-4,47}$$

$$N_d = 1,365 \times 10^{-9}(2,562 \times 10^{-4})^{-4,47}$$

$$N_d = 15.444.859,46 \text{ ESAL}$$

From the calculation obtained, it is concluded that the condition of this alternative pavement can accommodate the load repetition up to 188.490.357,3 ESAL until fatigue cracking occurs. This alternative pavement design may also accommodate the load repetition of 4.068.121,79 ESAL until rutting occurs and can accommodate the load repetition of 15.444.859,46 ESAL until permanent deformation occurs. Based on the result above, the first distress occurs due to traffic load is rutting, which means the end of service life of the pavement design until the rutting occurs.

The further analysis result of the KENPAVE program calculation can be seen in the following Table 5.13 below.

Table 5.13 Stress and Strain Value of Alternative Pavement Design 1-3

Alternative Pavement Type	Load Point (X)	Horizontal P Strain	Vertical Strain	Vertical Strain
		At point 10,495 cm	At point 10,495 cm	At point 40,505 cm
1	1	$1,965 \times 10^{-4}$	$3,453 \times 10^{-4}$	$2,341 \times 10^{-4}$
	2	$1,774 \times 10^{-4}$	$1,877 \times 10^{-4}$	$2,533 \times 10^{-4}$
	3	$1,575 \times 10^{-4}$	$8,016 \times 10^{-5}$	$2,561 \times 10^{-4}$
2	1	$1,773 \times 10^{-4}$	$2,967 \times 10^{-4}$	$2,331 \times 10^{-4}$
	2	$1,652 \times 10^{-4}$	$1,817 \times 10^{-4}$	$2,513 \times 10^{-4}$
	3	$1,530 \times 10^{-4}$	$1,106 \times 10^{-4}$	$2,548 \times 10^{-4}$
3	1	$1,773 \times 10^{-4}$	$2,943 \times 10^{-4}$	$1,997 \times 10^{-4}$
	2	$1,622 \times 10^{-4}$	$1,790 \times 10^{-4}$	$2,167 \times 10^{-4}$
	3	$1,499 \times 10^{-4}$	$2,943 \times 10^{-4}$	$2,198 \times 10^{-4}$

The maximum value of strain for distress prediction can be seen in the following Table 5.14.

Table 5.14 Maximum Strain for Distress Prediction

Alternative Design	Distress Prediction		
	Fatigue Cracking	Rutting	Permanent Deformation
1	$1,965 \times 10^{-4}$	$3,453 \times 10^{-4}$	$2,562 \times 10^{-4}$
2	$1,773 \times 10^{-4}$	$2,967 \times 10^{-4}$	$2,548 \times 10^{-4}$
3	$1,773 \times 10^{-4}$	$2,943 \times 10^{-4}$	$2,198 \times 10^{-4}$

5.3.5 Road Service Life Prediction for the Alternative Pavement Designs

The analysis of the alternative pavement designs by the KENPAVE program with Elastic Linier modelling is in the following Table 5.15.

Table 5.15 Recapitulation Result of the KENPAVE Analysis of the Elastic Modelling

Damage Type	Alternative Design 1	Alternative Design 2	Alternative Design 3
	ESAL	ESAL	ESAL
Fatigue cracking	369.588.208,6	282.082.901,6	282.082.901,6
Rutting	4.068.121,79	8.014.440	8.310.749,264
Permanent Deformation	15.444.859,46	15.827.824	30.638.597,8

The load repetition results from the KENPAVE analysis are then compared to the CESA5 value calculation based on the load repetition according to the available traffic data, which can be calculated as follows.

$$CESA_{deform} = \sum (ADT_{vehicle\ type} \times VDF) \times 365 \times DD \times DL \times \frac{(1+0,01i)^{UR}-1}{0,01 \times 4,8}$$

$$\begin{aligned}
 8.310.749,26 &= (102 \times 1,3) \times 36 \quad 1 \times \frac{(1 + 0,01 \times 4,83\%)^{UR} - 1}{0,01 \times 4,83\%} \\
 &+ (84 \times 0,4) \times 365 \times 0,5 \times 1 \times \frac{(1 + 0,01 \times 4,83\%)^{UR} - 1}{0,01 \times 4,83\%} \\
 &+ (1.314 \times 2,2) \times 365 \times 0,5 \times 1 \times \frac{(1 + 0,01 \times 4,83\%)^{UR} - 1}{0,01 \times 4,83\%} \\
 &+ (676 \times 17,2) \times 365 \times 0,5 \times 1 \times \frac{(1 + 0,01 \times 4,83\%)^{UR} - 1}{0,01 \times 4,83\%}
 \end{aligned}$$

$$\approx 8,010 \text{ years} = 8 \text{ years}$$

From the analysis of the alternative flexible pavement using Elastic modelling, the output is in the form of the maximum axle load that can be resisted by the Peureulak-Bts road in Langsa City, East Aceh. The service life for each alternative pavement design to accommodate the damages to the pavement can be seen in the following Table 5.16 below.

Table 5.16 The Service Life and ESAL Value of Alternative Pavement Designs

Type of Damage	Alternative Pavement Design		
	1	2	3
Fatigue Cracking	260 years	211 years	211 years
Rutting	4 years	8 years	8 years
Permanent Deformation	14 years	15 years	28 years

From the recapitulation table above, it can be concluded that the alternative - pavement design of the Peureulak-Bts road is going to experience rutting with the maximum axle load of 8.310.749,264 ESAL with service life of 8,010 years, which has not yet extended the planned service life for 20 years.

5.4 Discussion

There are the differences in thickness based on each of the alternative pavement designs is in the following Table 5.17 below.

Table 5.17 Alternative Pavement Thickness Each Layer (Design 1-3)

No	Foundation Type	Layer	Thickness (mm)
1	150mm CTB	AC-WC	40
		AC-BC	65
		CTB	150
		LFA Class B	150
		Selected Coarse-grained Fill/LFA Class C/Cement Stabilization	200

**Continuation of Table 5.17 Alternative Pavement Thickness Each Layer
(Design 1-3)**

No	Foundation Type	Layer	Thickness (mm)
2	200mm CTB	AC WC	50
		AC BC	80
		CTB	200
		LFA Class B	150
		Selected Coarse-grained Fill/LFA Class C/Cement Stabilization	200
3	250mm CTB	AC-WC	50
		AC-BC	80
		CTB	250
		LFA Class B	150
		Selected Coarse-grained Fill/LFA Class C/Cement Stabilization	200

The illustration to the alternative pavement designs obtained can be seen in the following Figure 5.9, Figure 5.10, and Figure 5.11 below.

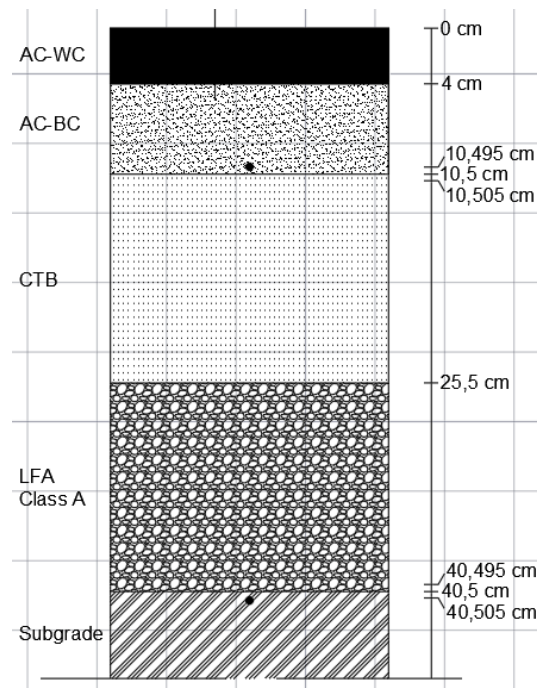


Figure 5.9 Alternative Pavement Design 1 with 150mm CTB

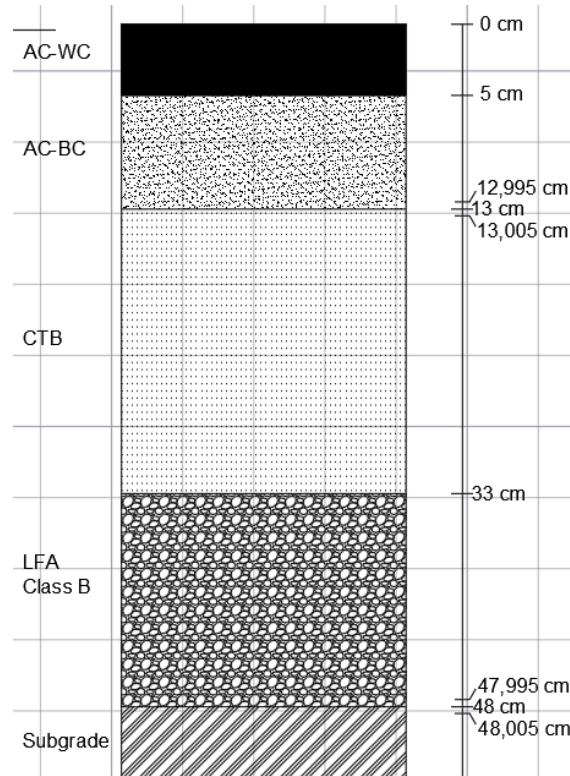


Figure 5.10 Alternative Pavement Design 2 with 200mm CTB

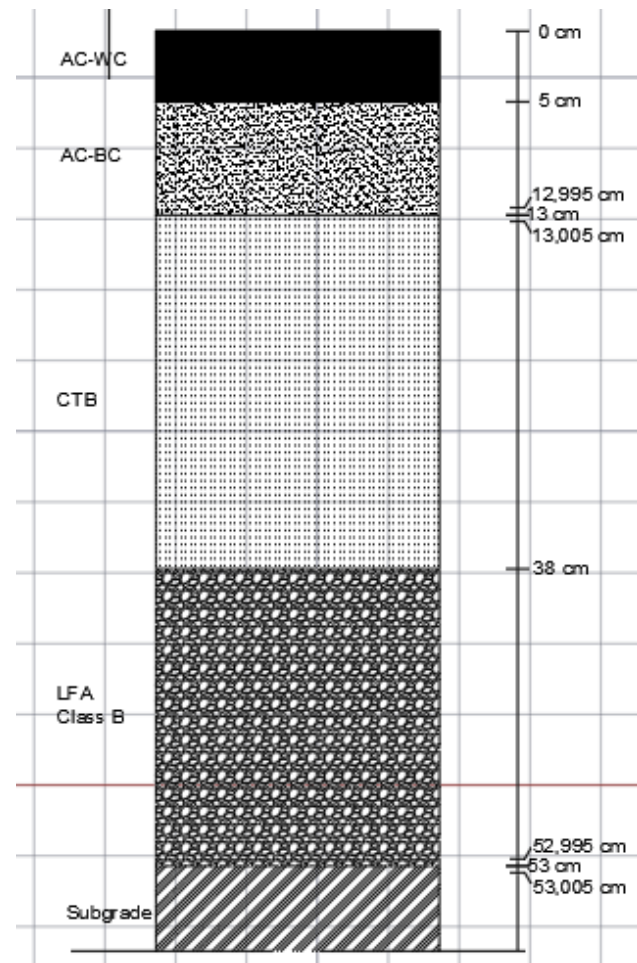


Figure 5.11 Alternative Pavement Design 3 with 250mm CTB

The best alternative is the CTB 150cm with fatigue cracking resistance up to 260 years in service life. If compared to study conducted by Zuasri (2024), the difference is shown in the following Table 5.18.

Table 5.18 Comparison to the Previous Study Result by Zuasri (2024)

Sabella (2024)		Zuasri (2024)	
Alternative Design		Alternative Design	
Layer	Thickness (mm)	Layer	Thickness (mm)
AC-WC	40	AC-WC	40
AC-BC	80	AC-BC	80
CTB	150	AC Base	100
LFA Class A	150	CTB	150
Selected coarse-grained Fill/LFA Class C/Cement Stabilization	200	LFA Class B	150
		Selected coarse-grained Fill/LFA Class C/Cement Stabilization	150

CHAPTER 6

CONCLUSION AND SUGGESTION

6.1 Conclusion

After conducting the analysis of the alternative pavement designs to Peureulak – Bts Road section KM 7+750 – 16+500 in Langsa City, East Aceh, several conclusions are obtained as follows.

1. The alternative pavement designs to the Peureulak – Bts Road section KM 7+750 – 16+500 in Langsa City, East Aceh can be seen in the following table.

Table 6.1 Recapitulation of Alternative Pavement Designs Thickness for Each Layer (Design 1-3)

Materials	Alternative Pavement Design		
	Thickness (mm)		
	1	2	3
AC-WC	40	50	50
AC-BC	65	80	80
CTB	150	200	250
LFA Class B	150	150	150
Selected Coarse- grained Fill/LFA Class C/Cement stabilization	200	200	200

2. The stress and strain responses of the Peureulak – Bts Road section KM 7+750 – 16+500 in Langsa City, East Aceh can be seen in the following Table 6.2.

Table 6.2 Recapitulation of Maximum Strain for Distress Prediction for each Alternative Pavement Design

Alternative Pavement Design	Distress Prediction		
	Fatigue Cracking	Rutting	Permanent Deformation
1	$1,965 \times 10^{-4}$	$3,453 \times 10^{-4}$	$2,562 \times 10^{-4}$
2	$1,773 \times 10^{-4}$	$2,967 \times 10^{-4}$	$2,548 \times 10^{-4}$
3	$1,773 \times 10^{-4}$	$2,943 \times 10^{-4}$	$2,198 \times 10^{-4}$

3. The recapitulation of distress in ESA value to the alternative pavement design according to the average traffic data and Bina Marga 2024 can be seen in the following Table 6.3.

Table 6.3 Recapitulation of Distress of The Alternative Pavement Design According to Average Traffic Data and Bina Marga 2024

Damage Type	Alternative Design 1	Alternative Design 2	Alternative Design 3
	ESAL	ESAL	ESAL
Fatigue cracking	369.588.208,6	282.082.901,6	282.082.901,6
Rutting	4.068.121,79	8.014.440	8.310.749,264
Permanent Deformation	15.444.859,46	15.827.824	30.638.597,8

4. The best alternative pavement design to the Peureulak – Bts Road section KM 7+750 – 16+500 in Langsa City, East Aceh can be seen in the following table Table 6.4.

Table 6.4 Alternative Design for Peureulak – Bts road in East Aceh

Layer	Thickness (mm)
AC-WC	50
AC-BC	80
CTB	250
LFA Class B	150
Selected Coarse-gra /LFA Class C/Cement Stabil	200

6.2 Suggestion

From the results of the analysis the author has conducted, the suggestions given are as follows.

1. The possibility of overloading vehicles should be considered due to high occurrences in Indonesia due to the lack of regulation and inspection.
2. The future alternative designs need to be reconsidered using other different methods to guarantee safer and more efficient alternatives.
3. It is obligatory to conduct a comparative calculation based on cost to find out the most efficient and effective alternative pavement type.

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