JOURNAL OF LIFESTYLE
& SDG'S REVIEW

e-ISSN: 2965-730X

# ROAD PAVEMENT REPAIR METHODS TO ACHIEVE SDG-9: DUE TO THE IMPACT OF OVERLOADING VEHICLES ON JORR E TOLL ROAD

Johanson Pardomuan Pardede [1]
Leksmono Suryo Putranto [2]
Ridho Bayu Aji [3]

## ABSTRACT

**Objective:** This study aims to analyze the ideal rigid pavement thickness for Jakarta Outer Ring Road (JORR) E under overloading conditions, ensuring the road's longevity and safety for both passenger and heavy vehicles, in alignment with Sustainable Development Goal (SDG) 9: Industry, Innovation, and Infrastructure.

**Theoretical Framework:** The research draws upon the concepts of pavement design and load equivalency, specifically utilizing the Equivalent Single Axle Load (ESAL) method and the AASHTO 1993 framework to assess the impact of overloading on pavement performance.

**Method:** The study employs a quantitative approach, calculating the pavement thickness using traffic data, axle load surveys, and structural performance models. The ESAL method quantifies the impact of overloading, while the AASHTO 1993 method determines the necessary pavement thickness to accommodate excessive loads.

**Results and Discussion:** The findings indicate that overloading has reduced the design life of JORR E from 40 years to only 15 years. To counteract this, the analysis suggests a required rigid pavement thickness of 16.95 inches (43.05 cm), significantly exceeding the standard thickness of 30 cm. These results underscore the urgency of addressing overloading through structural and regulatory measures to ensure sustainable infrastructure development, supporting SDG 9.

**Research Implications:** This study provides critical insights into the necessity of adapting pavement design to local traffic conditions. The findings could inform policymakers and engineers in creating more durable road systems, mitigating the adverse effects of overloading, and promoting sustainable infrastructure.

**Originality/Value:** By integrating theoretical and empirical analyses, this research offers a novel perspective on the intersection of traffic engineering and infrastructure sustainability, specifically addressing the challenges posed by overloading in urban toll road networks and contributing to SDG 9.

**Keywords:** toll road, rigid pavement, heavy vehicle, overloading, pavement thickness, sdg 9, sustainable infrastructure, sustainable development goals (SDGs).

**Received:** Oct/11/2024
**Accepted:** Dec/13/2024
**DOI:** https://doi.org/10.47172/2965-730X.SDGsReview.v5.n01.pe04171

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[1] Tarumanegara University, Jakarta, Indonesia. E-mail: acon.p66@gmail.com
[2] Tarumanegara University, Jakarta, Indonesia. E-mail: lexy_putranto@yahoo.co.id
[3] Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia. E-mail: bayuaji@its.ac.id

## 1 INTRODUCTION

The Jakarta Outer Ring Road (JORR) E was developed to improve traffic flow and facilitate efficient logistics access from southern Tangerang and Bogor to Tanjung Priok Port. Prior to its construction, logistics transportation required approximately six hours of travel. With the development of JORR E, travel time has been significantly reduced to two to three hours, enhancing regional connectivity and promoting economic growth.

However, the performance of JORR E has been compromised by the continuous passage of overloaded vehicles, particularly heavy-duty trucks, which accelerate the deterioration of the road. Overloading reduces the structural integrity of the pavement, resulting in premature wear, increased repair costs, and diminished safety and comfort for road users. According to studies by Gao *et al*. (2024) and Anwar & Tamin (2021), overloading is a key factor that reduces the design life of the toll road, initially planned for 40 years (Júnior *et al*., 2020).

To quantify the impact of overloading, data from the Weigh-in-Motion (WIM) system installed on JORR E was analyzed. The WIM data, provided by Jasa Marga, includes vehicle type, axle configuration, and total weight of overloaded vehicles (Burnos *et al*., 2021). Using this data, the Vehicle Damage Factor (VDF) and Equivalent Single Axle Load (ESAL) were calculated, which formed the basis for determining the cumulative ESAL (CESA) and assessing the road's actual design life.

The issue of overloading and its impact on infrastructure sustainability aligns with broader challenges in managing construction delays and mitigating risks in project management. *For instance, delays in infrastructure projects, as highlighted in the study by Riau et al. (2024), are often attributed to inadequate resource planning and risk management. Their research emphasizes the importance of adhering to construction schedules and implementing sanctions for non-compliance, which resonates with the need to enforce regulatory measures on overloaded vehicles traversing JORR E.*

In addition to construction management challenges, infrastructure development also intersects with disaster mitigation and sustainable tourism.

*Research by Karim et al. (2025) demonstrates how disaster-resilient infrastructure and effective risk management strategies can enhance sustainability, especially in vulnerable regions like Morotai Island. While JORR E is not situated in a disaster-prone area, the concept of designing infrastructure with resilience in mind can be applied to address the long-term sustainability of toll roads facing overloading issues.*

Furthermore, *the integration of sustainability into infrastructure planning is supported by the study of (Balida et al., 2025), which highlights the significance of preserving infrastructure while fostering community well-being and tourism. Although their focus is on tourism development, their findings underscore the importance of aligning infrastructure projects with Sustainable Development Goals (SDGs), particularly SDG 9, which emphasizes building resilient infrastructure, promoting sustainable industrialization, and fostering innovation.*

This study aims to evaluate the effects of overloading on the lifespan of JORR E and determine the ideal pavement thickness required under current traffic conditions. By aligning the findings with Sustainable Development Goal (SDG) 9, which emphasizes sustainable infrastructure development, this research provides actionable recommendations to mitigate overloading's adverse effects and ensure the road's longevity and safety.

## 2 THEORETICAL FRAMEWORK

Overloaded vehicles are a significant factor contributing to the premature deterioration of roads. When vehicles exceed the allowable axle load, they have a substantial impact on road damage (Oyekanmi & Ejem, 2022). Overloading occurs when a vehicle's load exceeds the design load used in determining the pavement's structural capacity or the number of operational cycles before reaching its design life. This premature deterioration is often referred to as premature failure. The expected pavement service life, on the other hand, is defined as the number of load repetitions (in terms of Equivalent Single Axle Loads, ESAL) that a road can withstand before structural damage occurs to the pavement layer (Pais & Minhoto, 2018). Excessive loads can accelerate road damage due to exceeding the pavement's bearing capacity. This damage is primarily caused by excessive loading.

Excessive loads can accelerate road deterioration. Vehicles carrying excessive loads can cause the desired Cumulative Equivalent Single Axle Load (CESA) to be reached prematurely, shortening the road's design life. The design life of a pavement is defined as the number of years from the road's opening to traffic until structural repairs are required or an additional asphalt layer is needed to address surface imperfections (O'Flaherty, 2014).

The impact of axle loads on pavement damage is commonly referred to as the Vehicle Damage Factor (VDF) (Kumar *et al.*, 2020). VDF represents the ratio of the damage caused by a single axle load of a vehicle to a standard single axle load of 8.16 tons (Sharma *et al.*, 1995). This is the basis for calculating the level of road damage caused by axle loads. According to Burnos *et al.* (Burnos *et al.*, 2021), a corresponding model equation has been developed. To assess the level of damage, it is necessary to evaluate the condition of the pavement, which is a crucial aspect in determining maintenance and repair activities. Factors such as the increasing weight of vehicles, especially trucks, and heavier loads significantly increase the VDF value, leading to a higher equivalent single axle load.

The level of damage caused by a vehicle's axle to the road is referred to as the damage value (Cebon, 1989). When applied to a standard 8.16-ton axle (single, tandem, triple), an ideal damage value is close to one. The Equivalent Single Axle Load (ESAL) of a vehicle is calculated by summing the ESAL of the front axle and the rear axle, as expressed in Equation 1.

$$ESAL = k\left[\frac{L}{8.16}\right] \qquad (1)$$

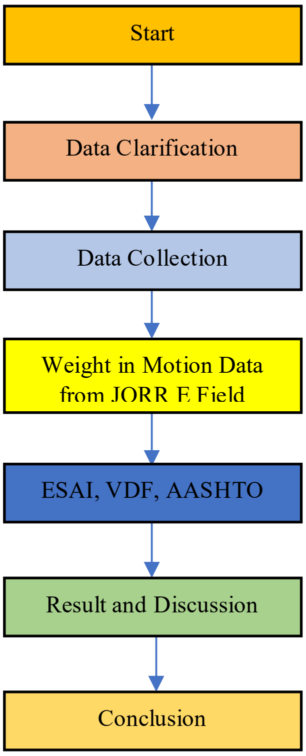
where:

ESAL = equivalent standard axle load,
L = single axle load of a vehicle (ton)
with k = 1 for single axle, k = 0.086 for tandem axle,
and k = 0.021 for triple axle.

The research stages to calculate the design life of the JORR Section E toll road involve clarifying the data obtained from Jasa Marga for the JORR Section E toll road. This clarification is done to facilitate further data processing. Subsequently, the design life calculation is carried out using the formula obtained from the Pavement Manual of the Directorate General of Highways (Figure 1).

**Figure 1**

*Process flowchart*



The data obtained is secondary WIM data collected by Jasa Marga at the JORR Section E location. The JORR Section E toll road stretches from Bambu Apus to Rorotan, and it is heavily traversed by heavy vehicles, including those exceeding the standard axle load (Figure 2).

**Figure 2**

*Map of the WIM Network on the Trans Java Toll Road*

The data used for the calculation is the WIM data collected at the JORR Section E location, installed on the JORR Section E toll road. The WIM data capturing vehicles exceeding the weight limit is reported to the Traffic Corps for subsequent ticketing by the police based on The Law Number 22 of 2009 Concerning Traffic and Road Transport.

## 3 METHODOLOGY

### 3.1 FIELD DATA

To determine the number of overloaded vehicles, WIM data was used to ascertain the number of vehicles passing through the JORR Section E toll road per day. This data is recorded in the WIM application installed on the JORR Section E toll road (KM 53+600 B). As shown in Table 1 below, lane B is divided into three lanes, and each lane records data on vehicles exceeding the weight limit.

**Table 1**

*WIM Data for JORR Section E*

| Subclass | Vehicle Classes | Lane 1 | Lane 2 | Lane 3 | Sum | average daily traffic |
|---|---|---|---|---|---|---|
| 10 | I | 64 | 133 | 9 | 206 | 7 |
| 20 | I | 1,021 | 1,959 | 755 | 3,735 | 125 |
| 30 | I | 2,564 | 8,052 | 1,367 | 11,983 | 399 |
| 31 | I | 41 | 39 | 1 | 81 | 3 |
| 32 | I | 41 | 32 | - | 73 | 2 |
| 33 | I | 1,138 | 637 | 4 | 1,779 | 59 |
| 40 | II | 8,174 | 18,666 | 1,504 | 28,344 | 945 |
| 41 | I | 3,697 | 7,471 | 1,940 | 13,108 | 437 |
| 50 | III | 83 | 67 | 2 | 152 | 5 |
| 51 | III | 15,613 | 17,098 | 449 | 33,160 | 1,105 |
| 56 | I | 716 | 665 | 25 | 1,406 | 47 |
| 57 | IV | 454 | 444 | 44 | 942 | 31 |
| 58 | IV | 225 | 199 | 9 | 433 | 14 |
| 59 | V | 191 | 344 | 22 | 557 | 19 |
| 60 | V | 846 | 827 | 9 | 1,682 | 56 |
| 61 | V | 881 | 482 | 22 | 1,385 | 46 |
| 62 | V | 15,159 | 25,402 | 293 | 40,854 | 1,362 |
| 63 | V | 2,309 | 2,749 | 28 | 5,086 | 170 |
| 70 | V | 112 | 188 | 4 | 304 | 10 |
| 71 | V | 58 | 45 | 2 | 105 | 4 |
| 100 | V | 863 | 1,058 | 40 | 1,961 | 65 |
| 101 | V | 1,106 | 3,333 | 82 | 4,521 | 151 |
| 102 | V | 7,949 | 14,185 | 190 | 22,324 | 744 |
| 110 | V | 24 | 23 | 2 | 49 | 2 |
| 111 | V | 325 | 383 | 6 | 714 | 24 |
| 112 | V | 49 | 65 | - | 114 | 4 |
| 113 | V | 29 | 13 | - | 42 | 1 |
| 120 | V | 5,122 | 8,456 | 105 | 13,683 | 456 |
| **Sum** | | **68,854** | **113,015** | **6,914** | **188,783** | **6,293** |

To calculate LHR:

$$LHR = \frac{Total\ number\ of\ vehicles}{30}\ hr \qquad (2)$$

3.2 AVERAGE DAILY TRAFFIC VOLUME

Table 2 presents the Average Daily Traffic (ADT) data based on vehicle sub-class and category that passed through the JORR Section E toll road. This data was obtained from the WIM results on the JORR Section E toll road.

**Table 2**

*Vehicle Class and Average Daily Traffic on JORR Section E Toll Road*

| Sub Class | Vehicle Classes | Average Daily Traffic |
|---|---|---|
| 10 | I | 7 |
| 20 | I | 125 |
| 30 | I | 399 |
| 31 | I | 3 |
| 32 | I | 2 |
| 33 | I | 59 |
| 40 | II | 945 |
| 41 | I | 437 |
| 50 | III | 5 |
| 51 | III | 1105 |
| 56 | I | 47 |
| 57 | IV | 31 |
| 58 | IV | 14 |
| 59 | V | 19 |
| 60 | V | 56 |
| 61 | V | 46 |
| 62 | V | 1362 |
| 63 | V | 170 |
| 70 | V | 10 |
| 71 | V | 4 |
| 100 | V | 65 |
| 101 | V | 151 |
| 102 | V | 744 |
| 110 | V | 2 |
| 111 | V | 24 |
| 112 | V | 4 |
| 113 | V | 1 |
| 120 | V | 456 |
| **Sum** | | **6,293** |

## 3.3 OVERLOAD VEHICLE DATA

To calculate the equivalent value of overloaded vehicles, the data used is from the WIM on JORR Section E toll road at KM 53+600, lane B. As seen in Table 3, the WIM data is divided into four overload classifications, starting from the lowest at 5% to the highest. Values above 100% indicate that the vehicle's load weight has exceeded the standard permitted limit.

**Table 3**

*Average Daily Traffic of Overloaded Vehicles*

| Sub Class | Overloaded Traffic Vehicles Average Daily | | | |
|---|---|---|---|---|
| | 5%-20% | 20%-50% | 50%-100% | 100% |
| 10 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 |
| 30 | 69 | 94 | 46 | 0 |
| 31 | 0 | 0 | 0 | 0 |
| 32 | 0 | 0 | 0 | 1 |
| 33 | 0 | 1 | 5 | 7 |
| 40 | 28 | 22 | 16 | 60 |
| 41 | 16 | 9 | 10 | 3 |
| 50 | 0 | 0 | 0 | 0 |
| 51 | 43 | 118 | 376 | 150 |
| 56 | 3 | 9 | 10 | 1 |
| 57 | 6 | 12 | 2 | 1 |
| 58 | 2 | 3 | 2 | 0 |
| 59 | 2 | 3 | 8 | 2 |
| 60 | 0 | 2 | 5 | 6 |
| 61 | 1 | 1 | 1 | 0 |
| 62 | 80 | 18 | 2 | 0 |
| 63 | 4 | 2 | 0 | 0 |
| 70 | 0 | 0 | 0 | 0 |
| 71 | 0 | 0 | 1 | 0 |
| 100 | 0 | 1 | 0 | 0 |
| 101 | 1 | 2 | 1 | 0 |
| 102 | 11 | 9 | 2 | 0 |
| 110 | 0 | 0 | 0 | 0 |
| 111 | 0 | 1 | 1 | 0 |
| 112 | 0 | 0 | 0 | 0 |
| 113 | 0 | 0 | 0 | 0 |
| 120 | 36 | 47 | 4 | 0 |
| **Sum** | **305** | **10580** | **493** | **233** |

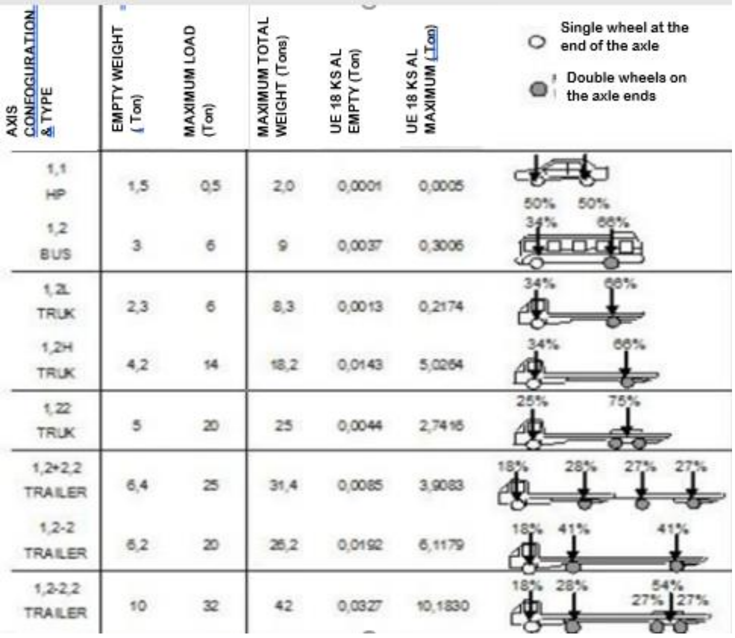
## 3.4 PERMITTED GROSS VEHICLE WEIGHT

Figure 3 below shows the axle configuration of each vehicle type expected to use the toll road, along with their corresponding permitted gross vehicle weight (GVW). The permitted GVW increases with the number of axles. This can be expressed by the formula: GVW = Curb Weight (CW) + Weight of Occupants (WO) + Payload (PL). The GVW is set by the government, considering the load-bearing capacity of the weakest road section, tire strength, and axle design strength to increase road life and improve road safety. Meanwhile, the Gross Vehicle Mass (GVM) is determined by the manufacturer based on the axle design strength, ensuring that the GVW does not exceed the GVM.

From Figure 3, the curb weight and maximum permissible weight for vehicles passing through the toll road can be obtained, considering the axle configuration and the load-bearing capacity of each single or tandem axle.

**Figure 3**

*Map of the WIM Network on the Trans Java Toll Road*



| AXIS CONFOGURATION & TYPE | EMPTY WEIGHT ( Ton) | MAXIMUM LOAD (Ton) | MAXIMUM TOTAL WEIGHT (Tons) | UE 18 KS AL EMPTY (Ton) | UE 18 KS AL MAXIMUM ( Ton) | ○ Single wheel at the end of the axle<br>● Double wheels on the axle ends |
|---|---|---|---|---|---|---|
| 1,1<br>HP | 1,5 | 0,5 | 2,0 | 0,0001 | 0,0005 | 50% 50% |
| 1,2<br>BUS | 3 | 6 | 9 | 0,0037 | 0,3006 | 34% 66% |
| 1,2L<br>TRUK | 2,3 | 6 | 8,3 | 0,0013 | 0,2174 | 34% 66% |
| 1,2H<br>TRUK | 4,2 | 14 | 18,2 | 0,0143 | 5,0264 | 34% 66% |
| 1,22<br>TRUK | 5 | 20 | 25 | 0,0044 | 2,7416 | 25% 75% |
| 1,2+2,2<br>TRAILER | 6,4 | 25 | 31,4 | 0,0085 | 3,9083 | 18% 28% 27% 27% |
| 1,2-2<br>TRAILER | 6,2 | 20 | 26,2 | 0,0192 | 6,1179 | 18% 41% 41% |
| 1,2-2,2<br>TRAILER | 10 | 32 | 42 | 0,0327 | 10,1830 | 18% 28% 54% 27% 27% |

3.5 DESIGN TRAFFIC LOAD

The construction of toll roads involves receiving traffic loads transmitted through vehicle wheels. The magnitude of the load transferred depends on the total vehicle weight, axle configuration, contact area between the wheel and the road surface, vehicle speed, and other factors (Kakara *et al.*, 2020). Heavy vehicles generally have different total weights, depending on the load being transported. This load is distributed on the road through vehicle axles and wheels. As the load increases, more axles are required to ensure that the axle load does not exceed the design capacity. The load on each axle is determined by the axle load and vehicle configuration. The expected traffic load, according to The Law Number 22 of 2009 Concerning Traffic and Road Transport, traffic is defined as the movement of vehicles and people in road traffic space, while road traffic space means infrastructure intended for traffic of vehicles, people, and/or goods in the form of roads and related facilities. Daily traffic volume data does not reflect the repetition of traffic loads received by the road structure. The repetition of traffic loads on the planned lane is determined by considering the volume and distribution of different vehicle types on each lane. The formula for determining the design traffic load repetitions for different vehicle types and axle configurations can be seen in the equation.

$$Q = \sum LHR_i \; C \; DL \qquad (3)$$

Q = design lane traffic repetition, vehicles/day/lane: Q represents the number of times a design lane is subjected to traffic load, expressed as vehicles per day per lane.C = directional distribution coefficient: C is a coefficient that indicates the distribution of traffic in a specific direction. DL = design lane distribution coefficient: DL is a coefficient that indicates the distribution of traffic to the design lane. LHRTi = annual average daily traffic for vehicle type i, vehicles/day/2 directions: LHRTi represents the average number of vehicles of type i passing through a section of road in both directions per day over a year. Single-axle single-wheel (STRT): A single axle with a single wheel on each side. Single-axle dual-wheel (STRG): A single axle with dual wheels on each side. Tandem axle single-wheel (STdRG): A tandem axle (two axles close together) with single wheels on each side. Tridem axle dual-wheel (STrRG): A tridem axle (three axles close together) with dual wheels on each side.

### 3.6 EQUIVALENT AXLE LOAD NUMBER

The equivalent axle load number (E) is a value that represents the ratio of the damage caused by a load path on a single vehicle axle to the damage caused by a load path on a single vehicle axle weighing 8.16 tons (18,000 pounds) (Sharma *et al*., 1995).

$$E = \frac{L^4}{8160} \qquad (4)$$

$$E = 0{,}086\frac{L^4}{8160} \qquad (5)$$

where:

*E = Equivalent axle load;*
*L = Axle load*

## 3.7 SERVICE LIFE

Service Life The design life is the number of years from the time a road is opened to traffic until it requires repair. Repairs can be major repairs or new surface overlays. Routine pavement maintenance must be carried out throughout the design life. For example, adding non-structural layers that serve as wear courses (O'Flaherty, C. A. (2002). The cumulative standard axle load or cumulative equivalent standard axle load (CESAL) during the design life is calculated using equation 6.

$$W_{18} = \sum LHR_j \; VDF_j \; \frac{N_n}{N_i} \; DD \; DL \; 365 \qquad (6)$$

Where:

W18 = Traffic design on the traffic lane (ESAL);
LHRj = Average daily traffic for a specific vehicle type (vehicles per day);
VDFj = Vehicle Damage Factor for each vehicle type;
DL = Lane distribution factor;
Ni = Traffic in the first year the road is opened;
Nn = Traffic at the end of the design life.

## 3.8 GROWTH FACTOR

The traffic growth factor is calculated by estimating the duration of traffic use, resulting in a traffic growth rate corresponding to the design life of the pavement. To calculate the growth factor over the design life, refer to equation 7 as follows:

$$Np = \frac{(1+i)^{\mathrm{u}} r - 1}{i} \qquad (7)$$

## 3.9 REMAINING DESIGN LIFE

Remaining Life refers to the reduction in the expected service life due to the load of passing vehicles. The service life of the road is expected to end according to the expected service life (Cerea, 2011). However, it is not uncommon for vehicles passing by to carry loads exceeding the limit. This causes the road to fatigue faster. Therefore, it is necessary to calculate the remaining life (RL) based on the reduction in the road's service life. The remaining life can be calculated using equation 8, as follows:

$$RL = 100\left[1 - \frac{(N_p)}{N_{1.5}}\right] \qquad (8)$$

## 3.10 DESIGN CALCULATION FOR RIGID PAVEMENT THICKNESS IMPROVEMENT USING AASHTO 1993

A road pavement on a toll road is a structure located above the base and vehicle wheels, serving to reduce stress on the subgrade to an allowable limit. The function of the pavement is to safely and comfortably carry traffic loads and to prevent significant damage throughout its design life, to protect the subgrade from water erosion, and to serve as an intermediate layer to distribute traffic loads to the subgrade (Walsh *et al.*, 2011).

The AASHTO 1993 method, according to El-badawy *et al.* (2011), originated in the United States and is one of the most commonly used methods for designing pavement thickness. This method has been widely adopted globally for planning and is standardized in several countries. The AASHTO 1993 method is essentially an empirical design method. Parameters required for planning using the AASHTO 1993 method include Structural number (SN), traffic, reliability, environmental factors, and serviceability.

The AASHTO 1993 method is used to calculate the ideal pavement thickness for roads continuously traversed by overloaded vehicles.

Data used for AASHTO 1993 calculations for the JORR E Toll Road is obtained from the calculation of excess ESAL of 12,321,546.38.

To determine the actual pavement layer thickness due to excessive loads passing through the JORR E toll road, equation 9 is used, as follows:

$$\mathrm{LogW18} = \mathrm{Z_R So} + 7{,}35\mathrm{Log}\,(\mathrm{D}+1) - 0{,}06 + \frac{log[\frac{\Delta PSI}{4{,}5-1{,}5}]}{\frac{1+1{,}624\ x\ 10^{7}}{(D+1)^{8{,}46}}} + (4{,}22 - 0{,}32\mathrm{Pt})\log\left\{\frac{S_c\, C_d\,(D^{0{,}75}-1{,}132\,)}{215{,}63\,[\frac{D^{0{,}75}-18{,}42}{(\frac{E_c}{k})}}\right\} \quad (9)$$

Where:

W18 = Traffic design Equivalent Single Axle Load (ESAL),
ZR = Standard normal deviate,
So = Standard deviation,
D = Concrete slab thickness (inches),
ΛPSI = Serviceability loss = (p0 - pi),
p0 = initial serviceability,
pi = Terminal serviceability Index,
Sc = Drainage coefficient,
J = Load transfer coefficient,
E0 = Modulus of elasticity (psi),
k = Subgrade reaction modulus (pci)

## 4 RESULT AND DISCUSSION

### 4.1 ANALYSIS OF EQUIVALENT CALCULATIONS FOR SUBCLASSES, VEHICLE TYPES, VEHICLE CONFIGURATIONS, AND NUMBER OF AXLES

Based on Table 4, which shows the axle configuration and the percentage of load on each axle for vehicles passing through the JORR E Toll Road section, equivalent calculations were performed for each vehicle class. The resulting equivalent values for each class are obtained.

## Table 4

*Equivalent Axle Load Analysis*

| No | Sub Class | Vehicle Type | Vehicle Axle Configuration | Number of Vehicle Axles | permitted weight amount | | Percentage Load Each Axle ( %) | | | | vehicle axle equivalent | | | | Total Equivalent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | STRT | STRG | SGRG/S TdRG | STrRG | STRT | STRG | SGRG/S TdRG | STrRG | |
| 1 | 10 | Sedan | 1.1 | 2 | 3 | Ton | 50% | | | | 0.01191 | | | | 0.01191 |
| 2 | 20 | Jeep | 1.1 | 2 | 3 | Ton | 50% | | | | 0.01191 | | | | 0.01191 |
| 3 | 30 | Kendaraan penumpang | 1.1 | 2 | 5 | Ton | 50% | | | | 0.09188 | | | | 0.09188 |
| 4 | 31 | Pick Up | 1.1 | 2 | 4 | Ton | 50% | | | | 0.03763 | | | | 0.03763 |
| 5 | 32 | Truk engkel kecil | 1.1 | 2 | 6 | Ton | 50% | | | | 0.19052 | | | | 0.19052 |
| 6 | 33 | Truck material | 1.1 | 2 | 6 | Ton | 50% | | | | 0.19052 | | | | 0.19052 |
| 7 | 40 | Truck besar engkel | 1.2 | 2 | 16 | Ton | 34% | 66% | | | 1.02996 | 2.80476 | | | 3.83472 |
| 8 | 41 | Bus kecil | 1.1 | 2 | 6 | Ton | 50% | | | | 0.19052 | | | | 0.19052 |
| 9 | 50 | Truck tronton | 1.2.2 | 3 | 25 | Ton | 25% | | 75% | | 1.79451 | | 3.44771 | | 5.24222 |
| 10 | 51 | Truck engkel trailer | 1.2.2. | 3 | 25 | Ton | 8% | 41% | | | 0.01882 | 4.97926 | | | 4.99808 |
| 11 | 56 | Pengangkut semen | 1.1 | 2 | 6 | Ton | 50% | | | | 0.19052 | | | | 0.19052 |
| 12 | 57 | Truk Engkel Trailer | 1.2.1.1 | 4 | 28 | Ton | 18% | 46% | | | 0.75883 | 12.41460 | | | 13.17344 |
| 13 | 58 | Truk Engkel Gandeng | 1.2.2.2 | 4 | 35 | Ton | 18% | 28% | | | 1.85262 | 6.24115 | | | 8.09378 |
| 14 | 59 | Truk Tribal ( truck kayu) | 1.1.2.2.2 | 5 | 35 | Ton | 18% | | | 64% | 3.70525 | | | 2.17273 | 5.87798 |
| 15 | 60 | Truk Tribal ( truck kayu) | 1.1.2.2.2 | 5 | 35 | Ton | 18% | | | 64% | 3.70525 | | | 2.17273 | 5.87798 |
| 16 | 61 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 17 | 62 | Truk Trontonr Gandeng | 1.2.2.2.2. | 5 | 40 | Ton | 8% | 21% | 41% | | 0.12332 | 2.04375 | 2.01791 | | 4.18498 |
| 18 | 63 | Truk Trontonr Gandeng | 1.2.2.2.2. | 5 | 40 | Ton | 8% | 21% | 41% | | 0.12332 | 2.04375 | 2.01791 | | 4.18498 |
| 19 | 70 | Truk Trontonr Gandeng | 1.2.2.2.2. | 5 | 40 | Ton | 8% | 21% | 41% | | 0.12332 | 2.04375 | 2.01791 | | 4.18498 |
| 20 | 71 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 21 | 100 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 22 | 101 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 23 | 102 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 24 | 110 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 25 | 111 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 26 | 112 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 27 | 113 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 28 | 120 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 29 | 113 | Truk Tronton Trailer | 1.2.2.2.2 | 5 | 40 | Ton | 18% | | 41% | | 3.16049 | | 2.01791 | | 5.17840 |
| 30 | 120 | Truk Engkel Trailer besar | 1.2.1.1.1 | 5 | 35 | Ton | 18% | 28% | | | 7.41049 | 2.08038 | | | 9.49088 |

Equivalent factor value of each vehicle axle:

$$STRT = E = \left[\frac{STRT(KN)^4}{53\ KN}\right] = 5{,}4\ ton \qquad (10)$$

$$STRG = E = \left[\frac{STRG(KN)^4}{80\ KN}\right] = 8{,}16\ ton \qquad (11)$$

$$STdRG = E = \left[\frac{STdRG(KN)^4}{135\ KN}\right] = 13{,}76\ ton \qquad (12)$$

$$STrRG = E = \left[\frac{STdRG(KN)^4}{181\ KN}\right] = 18{,}45\ ton \qquad (13)$$

## 4.2 ANALYSIS OF EQUIVALENT CALCULATIONS BASED ON THE IMPACT OF HEAVY VEHICLE OVERLOADS ON THE JORR E PAVEMENT

In Table 5, the equivalent value of each overload is calculated by multiplying the equivalent value from Table 6 with the LHR based on the overload for each class. The LHR overload data can be found in Table 3.

**Table 5**

*Calculation of equivalent axle load for overloaded vehicles*

| Sub Class | Equivalent Axle Load | | | |
|---|---|---|---|---|
| | 5%-20% | 20%-50% | 50%-100% | > 100% |
| 10 | - | - | - | - |
| 20 | - | - | - | - |
| 30 | 0.1905 | 0.4651 | 0.8617 | - |
| 31 | 0.0780 | - | 0.3530 | 0.6021 |
| 32 | - | - | 1.7869 | 3.0483 |
| 33 | 0.3951 | 0.9645 | 1.7869 | 3.0483 |
| 40 | 7.9517 | 19.4133 | 35.9654 | 61.3555 |
| 41 | 0.3951 | 0.9645 | 1.7869 | 3.0483 |
| 50 | - | - | 49.1663 | 83.8755 |
| 51 | 10.3640 | 25.3028 | 46.8765 | 79.9692 |
| 56 | 0.3951 | 0.9645 | 1.7869 | 3.0483 |
| 57 | 27.3164 | 66.6905 | 123.5524 | 210.7750 |
| 58 | 16.7833 | 40.9748 | 75.9108 | 129.5004 |
| 59 | 12.1886 | 29.7573 | 55.1290 | 94.0477 |
| 60 | 12.1886 | 29.7573 | 55.1290 | 94.0477 |
| 61 | 10.7379 | 26.2157 | 48.5678 | 82.8545 |
| 62 | 8.6780 | 21.1864 | 39.2505 | 66.9596 |
| 63 | 8.6780 | 21.1864 | 39.2505 | - |
| 70 | - | - | 39.2505 | - |
| 71 | - | - | 48.5678 | - |
| 100 | - | 26.2157 | 48.5678 | 82.8545 |
| 101 | 10.7379 | 26.2157 | 48.5678 | - |
| 102 | 10.7379 | 26.2157 | 48.5678 | - |
| 110 | 10.7379 | - | - | 82.8545 |
| 111 | 10.7379 | 26.2157 | 48.5678 | 82.8545 |
| 112 | 10.7379 | - | - | - |
| 113 | - | - | 48.5678 | 82.8545 |
| 120 | 19.6803 | 48.0476 | 89.0141 | - |
| **Sum** | | | | |

## 4.3 ANALYSIS EQUIVALENT SINGLE AXLE LOAD (ESAL) OF JORR E

Table 6 shows the calculated ESAL for each vehicle category, encompassing both compliant and overloaded vehicles. Four overload criteria from 0% to 100% are considered, and the total axle load for each category is determined.

## Table 6

*Determination of calculated ESAL for permitted and overloaded vehicles*

| Subclass | GOLONGAN KENDARAAN | LHR Normal | KENDARAAN KELEBIHAN BEBAN ( LHR) | | | | TOTAL LHR KELEBIHAN BEBAN | ESAL 2023 Jorr Seksi E ( diizinkan) | ESAL 2023 Jorr Seksi E | ESAL KELEBIHAN BEBAN 5 - 20 % | ESAL KELEBIHAN BEBAN 20 - 50 % | ESAL KELEBIHAN BEBAN 50 - 100 % | ESAL KELEBIHAN BEBAN 100% | TOTAL ESAL (OVERLOAD +SESUDAH PENGURANGAN )\ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 5 % - 20 % | 20% to 50% | 50% to 75% | > 100 % | | LHRxVDFxDDxDLx365 | LHRxVDFxDDxDLx365 | | | | | |
| | | A | B | C | D | E | F = (B+C+D+E) | G = ESA x A | H = ESA x (A -F) | I = ESA x B | J = ESA x C | K = ESA x D | L = ESA X E | M = (H + I + J + K + L) |
| 10 | I | 7 | 0 | 0 | 0 | 0 | 0 | 14.922 | 14.922 | - | - | - | - | 14.922 |
| 20 | I | 125 | 0 | 0 | 0 | 0 | 0 | 270.553 | 270.553 | - | - | - | - | 270.553 |
| 30 | I | 399 | 69 | 94 | 46 | 0 | 209 | 6,697.646 | 3,193.161 | 2,406.074 | 7,996.39 | 7,171.25 | - | 20,766.872 |
| 31 | I | 3 | 0 | 0 | 0 | 0 | 1 | 18.544 | 15.110 | 0.475 | - | 12.88 | 25.64 | 54.109 |
| 32 | I | 2 | 0 | 0 | 0 | 1 | 1 | 84.607 | 50.996 | - | - | 43.48 | 463.60 | 558.074 |
| 33 | I | 59 | 0 | 1 | 5 | 7 | 14 | 2,061.852 | 1,585.505 | 9.613 | 158.42 | 1,695.74 | 4,153.84 | 7,603.113 |
| 40 | II | 945 | 28 | 22 | 16 | 60 | 126 | 661,204.770 | 572,815.521 | 41,068.374 | 76,527.03 | 106,113.04 | 674,454.99 | 1,470,978.965 |
| 41 | I | 437 | 16 | 9 | 10 | 3 | 38 | 15,192.107 | 13,863.899 | 1,143.967 | 1,619.41 | 3,239.29 | 1,780.22 | 21,646.780 |
| 50 | III | 5 | 0 | 0 | 0 | 0 | 0 | 4,847.307 | 4,719.747 | - | - | 299.10 | 1,530.73 | 6,549.570 |
| 51 | III | 1105 | 43 | 118 | 376 | 150 | 686 | 1,008,228.747 | 382,433.690 | 80,385.871 | 545,202.89 | 3,213,528.29 | 2,187,211.80 | 6,408,762.535 |
| 56 | I | 47 | 3 | 9 | 10 | 1 | 23 | 1,629.547 | 813.615 | 249.942 | 1,607.67 | 3,195.81 | 593.41 | 6,460.445 |
| 57 | IV | 31 | 6 | 12 | 2 | 1 | 21 | 75,490.380 | 25,003.183 | 29,911.500 | 143,618.04 | 51,109.52 | 35,902.01 | 285,544.256 |
| 58 | IV | 14 | 2 | 3 | 2 | 0 | 8 | 21,319.685 | 10,241.327 | 6,227.987 | 22,682.94 | 32,325.34 | 2,363.38 | 73,840.978 |
| 59 | V | 19 | 2 | 3 | 8 | 2 | 15 | 19,917.049 | 4,004.864 | 4,893.715 | 17,197.23 | 76,128.60 | 32,611.04 | 134,835.447 |
| 60 | V | 56 | 0 | 2 | 5 | 6 | 13 | 60,144.482 | 46,413.518 | 963.914 | 8,327.08 | 48,628.40 | 102,982.23 | 207,315.140 |
| 61 | V | 46 | 1 | 1 | 1 | 0 | 3 | 43,630.205 | 40,700.523 | 1,698.384 | 5,900.71 | 8,568.16 | 504.03 | 57,371.809 |
| 62 | V | 1362 | 80 | 18 | 2 | 0 | 100 | 1,040,086.184 | 963,735.803 | 127,437.427 | 68,566.41 | 12,177.47 | 814.68 | 1,172,731.786 |
| 63 | V | 170 | 4 | 2 | 0 | 0 | 6 | 129,482.507 | 125,205.460 | 6,070.963 | 5,928.67 | 1,671.42 | - | 138,876.515 |
| 70 | V | 10 | 0 | 0 | 0 | 0 | 0 | 7,739.418 | 7,433.915 | - | - | 716.32 | - | 8,150.237 |
| 71 | V | 4 | 0 | 0 | 1 | 0 | 1 | 3,307.705 | 2,394.148 | - | - | 5,613.62 | - | 8,007.772 |
| 100 | V | 65 | 0 | 1 | 0 | 0 | 1 | 61,775.329 | 60,578.255 | - | 2,711.14 | 2,659.08 | 504.03 | 66,452.508 |
| 101 | V | 151 | 1 | 2 | 1 | 0 | 3 | 142,420.328 | 139,238.631 | 1,567.739 | 8,133.41 | 7,681.80 | - | 156,621.581 |
| 102 | V | 744 | 11 | 9 | 2 | 0 | 22 | 703,249.594 | 682,017.278 | 22,470.923 | 40,986.01 | 21,568.13 | - | 767,042.341 |
| 110 | V | 2 | 0 | 0 | 0 | 0 | 0 | 1,543.596 | 1,386.086 | 65.322 | - | - | 504.03 | 1,955.440 |
| 111 | V | 24 | 0 | 1 | 1 | 0 | 3 | 22,492.394 | 19,436.705 | 914.514 | 4,943.84 | 12,704.52 | 4,536.28 | 42,535.854 |
| 112 | V | 4 | 0 | 0 | 0 | 0 | 1 | 3,591.223 | 3,087.191 | 653.224 | - | - | - | 3,740.416 |
| 113 | V | 1 | 0 | 0 | 0 | 0 | 0 | 1,323.082 | 945.059 | - | - | 886.36 | 4,536.28 | 6,367.701 |
| 120 | V | 456 | 36 | 47 | 4 | 0 | 87 | 790,004.126 | 638,966.284 | 129,419.200 | 410,958.90 | 67,146.27 | - | 1,246,490.656 |
| **Sum** | | | | | | | **1383** | **4,827,767.89** | **3,750,565** | **457,559** | **1,373,066** | **3,684,884** | **3,055,472** | **12,321,546.38** |

The total ESAL before the overload was 4,827,767.89, while after calculating and summing the ESAL with the overload, the result was 12,351,436. Based on the figure above, the reduction in the design life of the JORR E Toll Road is calculated as follows: Reduction in design life = 12,351,436 / 4,827,767.89 = 2.55 years. This reduction is caused by the presence of overloaded vehicles traversing the JORR E Toll Road daily.

## 4.4 ANALYSIS OF REMAINING DESIGN

Life Calculation Design life due to actual overload, considering the design ESAL value and the ESAL resulting from overload.

$$W_{18} = \sum LHR_j \, VDF_j \, \frac{N_n}{N_i} \, DD \, DL \, (365 \; x \; Np) \qquad (14)$$

Where:

*$N_{1,5}$(ESAL) Com Normal = ESAL Normal x Growth period = 331,084,565*

$$RL = 100 \left[ 1 - \frac{(N_p)}{N_{1.5}} \right] \qquad (15)$$

Where:

L = Remaining Plan Life;
Np = Cumulative ESAL at the year;
$N_{1,5}$ = Cumulative ESAL at the end of the year

**Table 7**

*Design life Under overload Conditions*

| Tahun ke | IP ( ESAL) overloa | NI ( ESAL) Com Nor | RL (%) |
|---|---|---|---|
| 1 | 12,321,546 | 331,084,565.44 | 96.3 |
| 2 | 24,643,093 | 331,084,565.44 | 92.6 |
| 3 | 36,964,639 | 331,084,565.44 | 88.8 |
| 4 | 49,286,186 | 331,084,565.44 | 85.1 |
| 5 | 61,607,732 | 331,084,565.44 | 81.4 |
| 6 | 73,929,278 | 331,084,565.44 | 77.7 |
| 7 | 86,250,825 | 331,084,565.44 | 73.9 |
| 8 | 98,572,371 | 331,084,565.44 | 70.2 |
| 9 | 110,893,917 | 331,084,565.44 | 66.5 |
| 10 | 123,215,464 | 331,084,565.44 | 62.8 |
| 11 | 135,537,010 | 331,084,565.44 | 59.1 |
| 12 | 147,858,557 | 331,084,565.44 | 55.3 |
| 13 | 160,180,103 | 331,084,565.44 | 51.6 |
| 14 | 172,501,649 | 331,084,565.44 | 47.9 |
| 15 | 184,823,196 | 331,084,565.44 | 44.2 |
| 16 | 197,144,742 | 331,084,565.44 | 40.5 |
| 17 | 209,466,288 | 331,084,565.44 | 36.7 |
| 18 | 221,787,835 | 331,084,565.44 | 33.01 |
| 19 | 234,109,381 | 331,084,565.44 | 29.29 |
| 20 | 246,430,928 | 331,084,565.44 | 25.57 |
| 21 | 258,752,474 | 331,084,565.44 | 21.85 |
| 22 | 271,074,020 | 331,084,565.44 | 18.13 |
| 23 | 283,395,567 | 331,084,565.44 | 14.40 |
| 24 | 295,717,113 | 331,084,565.44 | 10.68 |
| 25 | 308,038,659 | 331,084,565.44 | 6.96 |
| 26 | 320,360,206 | 331,084,565.44 | 3.24 |
| 27 | 332,681,752 | 331,084,565.44 | -0.48 |

Table 7 shows that the design life of the JORR E toll road pavement, originally set at 40 years by the concessionaire, has decreased by 14 years due to overloaded vehicles passing through.

## 4.5 IMPACT OF OVERLOADING ON PAVEMENT DESIGN LIFE

As detailed in the results, the overloading of vehicles on the JORR E Toll Road has led to a significant reduction in the road's design life. The road, originally designed to last 40 years, has been reduced to just 15 years due to the impact of overloaded vehicles. Using the Equivalent Single Axle Load (ESAL) method, which quantifies the effects of overloading based on traffic data and axle load surveys, the cumulative ESAL for the toll road has increased dramatically. The total ESAL before the overloading was recorded at 4,827,767.89, and after accounting for overloaded vehicles, this figure increased to 12,351,436. This increase in ESAL has resulted in a 2.55-year reduction in the design life of JORR E.

*These findings align with broader challenges in infrastructure management. As highlighted in the study by Riau et al. (2024), inadequate planning and resource management often lead to reduced performance in infrastructure projects. Similar to the delays in construction schedules observed in their research, the lack of proper enforcement of vehicle load limits exacerbates the premature deterioration of JORR E. Enforcing regulatory measures, akin to construction sanctions proposed by Riau et al. (2024), is critical to addressing overloading issues.*

## 4.6 PAVEMENT THICKNESS ANALYSIS

To obtain the maximum result based on the AASHTO method according to equation 9 above, the calculation can be done using a worksheet or iteration to obtain a W18 value of 331,084,565.44 with a ratio of 1. In this calculation, an iteration is performed with the value of D (pavement thickness), resulting in 240 iterations. The value of D (pavement thickness) obtained is 16.55 inches or 43.05 cm.

**Table 8**

*Concrete Pavement Thickness Due to Overloading*

| | D | PCC MR | E | k-value | R | So | J | Cd | Pi | Pt | W18 | (W18calc/W18design) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5.00 | 463.9175258 | 3,730,000 | 160 | 90 | 0.35 | 2.8 | 1.225 | 4.5 | 2.5 | 223,979 | 0.00 |
| 2 | 5.05 | 463.9175258 | 3,730,000 | 160 | 90 | 0.35 | 2.8 | 1.225 | 4.5 | 2.5 | 235,251 | 0.00 |
| 3 | 5.10 | 463.9175258 | 3,730,000 | 160 | 90 | 0.35 | 2.8 | 1.225 | 4.5 | 2.5 | 246,977 | 0.00 |
| 4 | 5.15 | 463.9175258 | 3,730,000 | 160 | 90 | 0.35 | 2.8 | 1.225 | 4.5 | 2.5 | 259,170 | 0.00 |
| 5 | 5.20 | 463.9175258 | 3,730,000 | 160 | 90 | 0.35 | 2.8 | 1.225 | 4.5 | 2.5 | 271,844 | 0.00 |
| 237 | 16.80 | 463.9175258 | 3,730,000 | 160 | 90 | 0.35 | 2.8 | 1.225 | 4.5 | 2.5 | 310,733,154 | 0.94 |
| 238 | 16.85 | 463.9175258 | 3,730,000 | 160 | 90 | 0.35 | 2.8 | 1.225 | 4.5 | 2.5 | 317,057,508 | 0.96 |
| 239 | 16.90 | 463.9175258 | 3,730,000 | 160 | 90 | 0.35 | 2.8 | 1.225 | 4.5 | 2.5 | 323,492,864 | 0.98 |
| 240 | 16.95 | 463.9175258 | 3,730,000 | 160 | 90 | 0.35 | 2.8 | 1.225 | 4.5 | 2.5 | 330,040,858 | 1.00 |

To address the accelerated pavement deterioration caused by overloading, the study suggests that the required rigid pavement thickness for JORR E should be 16.55 inches (43.05 cm), significantly exceeding the current standard thickness of 11.81 inches (30 cm). This finding aligns with the analysis using the AASHTO method, which considers factors such as traffic load, pavement strength, and structural performance. The increased thickness is essential to accommodate the excessive loads imposed by heavy-duty and overloaded vehicles, ensuring the long-term stability and safety of the road.

*The need for increased pavement thickness is analogous to designing disaster-resilient* infrastructure *in high-risk areas. As Karim et al. (2025) emphasize, integrating resilience into infrastructure planning whether for disaster mitigation or accommodating overloading can significantly improve the longevity and sustainability of infrastructure. Although JORR E is not exposed to natural disasters, applying similar resilience principles in pavement design ensures its capacity to withstand extreme conditions imposed by overloaded vehicles.*

The analysis reveals that the most significant contributors to overloading are Tronton trucks (sub-class 50) and large single-axle trucks (sub-class 40), which significantly impact the road's deterioration. These vehicles, with their overloads exceeding 50%, account for the majority of the ESAL increase. Given the continuous passage of these heavy vehicles, addressing overloading is crucial to prevent further damage and ensure the road's functionality for future years.

## 5 CONCLUSION

The study highlights the critical impact of overloading on the JORR E Toll Road, leading to a significant reduction in its design life from 40 years to just 15 years. The increased ESAL due to overloaded vehicles has accelerated pavement deterioration, necessitating an adjustment in the required pavement thickness to accommodate these excessive loads. The optimal pavement thickness, as determined through the AASHTO method, is 16.55 inches (43.05 cm), well above the original 30 cm design thickness.

*These conclusions align with the findings of Balida et al. (2025), who emphasize the importance of integrating sustainability into infrastructure planning. While their research focuses on tourism-related infrastructure, the principles of sustainability and resilience are equally applicable to JORR E. By recalculating pavement thickness and enforcing load regulations, JORR E can better support its long-term functionality and contribute to achieving SDG 9's goals for sustainable infrastructure.*

To address this issue, the study recommends immediate action, including routine maintenance such as adding overlays to the pavement to prevent further deterioration. Additionally, if expansion of the JORR E toll road is considered in the future, recalculating the required pavement thickness based on the current overload conditions is essential to ensure the road's long-term viability. It is also recommended that regulations for calculating vehicle loads on toll roads be revised to account for the highest overload values, helping to sustain the infrastructure and support SDG 9 by promoting the development of resilient and sustainable infrastructure systems.

## ACKNOWLEDGEMENTS

We would like to express our thanks to the Tarumanegara University, which has supported this research.

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