The Overloading Effect on the Design Life of Road and Thickness of Pavement Layer

A Rahmawati¹, E Adly¹, I Lutfiyanto¹ and A Syifa M¹
¹Department of Civil Engineering, Faculty of Engineering, Universitas Muhammadiyah Yogyakarta, Jl. Brawijaya, Geblagan, Tamantirto, Kec. Kasihan, Bantul, Daerah Istimewa Yogyakarta, 55183 Indonesia.

* anita.rahmawati@umy.ac.id ; emil@umy.ac.id

Abstract. Solo-Yogyakarta KM 9-15 Road is the national highway, which supports the traffic of goods and services, but many passing goods transport vehicles do not match the allowable load. As a consequence, the damage on the pavement occurred. Therefore, this study aims to know the effect of overloading on design life and pavement thickness. This study used the method of Binamarga to analyze the effect of pavement thickness caused by overloading. The analysis was carried out by using the formula of design life decreasing with the value of Cumulative Equivalent Standard Axle (CESA) for overloading and standard load. Based on the 2013 Binamarga method, the design life is reduced by about eight years, from the previously determined is 20 years. Moreover, based on the analysis on pavement thickness of 20 years design life for a standard load, it showed that pavement thickness is needed for total surface layer is 100 mm consist of AC WC 40 mm and AC BC 60 mm. In addition, the base course layer is 145 mm (AC Base), and the subbase course layer is 300 mm (LPA Kelas A). At the same time, for overloading, the analysis result showed that it was required the pavement thickness for the surface layer is 100 mm, the base course layer is 180 mm, and the subbase course layer is 300 mm. These results indicate that overloading causes a reduction in the design life of the pavement and an increase in the thickness of the pavement.

Keywords: Bina Marga Method, Design Life, Overloading, Pavement Thickness

1. Introduction
The highway is one of transportation infrastructure that is intended for traffic and is very influential in the activities of daily life. Road plays an essential role in supporting services for various fields, one of which is the economy of a region. The increasing human needs in various aspects of life, it will impact on increasing traffic volume. This phenomenon will cause multiple problems on the road surface. The issues caused include damage to the road. Therefore, it will affect the level of comfort, safety, and smoothness in traffic.

Vehicles passing on roads, which bring load exceed the maximum specified load cause excessive loading on the pavement and affect the design life on the road [1]. Based on some previous studies, it can be concluded that the overloading can decrease the design life.

The study which using AASHTO 1993 and the calculation of cumulative ESAL (Equivalent Standard Axle Load) values, then the remaining pavement life was obtained. This section contains the
research background, purpose, contribution (the research benefit from theoretical and practical), research result and implication (Practical advice based on research result). The research result and implication in the introduction section are an only suggestion (not mandatory) [2].

Based on the design life of the 20-year plan, the cumulative ESAL value is 64,533,642 SAL, so there is a decrease in service life of eight years. The remaining life of the pavement plan is only 54.75%, and a pavement service life is reduced by 25.94%. Similar research on the effect of overloading were also not much different from previous research [3,4].

The research regarding the effect of overloading with slightly different methods showed that there was a reduction in service life from the design life and caused various road damage problems [5-14].

This study discussed the effect of overloading on design life and pavement thickness. Furthermore, this study used the method of Binamarga 2013 to analyze the decrease of service life and to analyze the effect of overloading on pavement thickness [15].

2. Literature Review

2.1. Axle Load and Overloading
The axle load of the vehicle is affected by a load of the vehicle and the axle configuration. Two similar vehicles will have different axle load because of the difference in load. Therefore, on road pavement planning, there needs to be a variation in axle loads so that that equivalent numbers can be determined for proper planning [16].

The amount of load received by the pavement depends on several things, i.e., the total weight of the vehicle, axle configuration, the contact area between the wheels and pavement and the speed of the vehicle. Overloading is a condition when the road receives a vehicle load that is not following the planned standard load. Researcher explained that the causes of road damage are overloading that repeatedly occurs, rainwater, air temperature, and poor quality pavement. The design of the road must be adequately planned and must also be adequately maintained so that it can serve the traffic load in accordance with the service life of the road [17].

2.2. Design Life
Based on the guidelines for flexible pavement of the Department Pekerjaan Umum (2013), the design life is the amount of time in the year calculated when the road is opened for vehicle traffic until heavy (structural) repairs need to be given, i.e., the new pavement layer (overlay). The design life used for the construction of new pavement is 20 years, and design life for road improvement is ten years [15].

The equation used to determine the Rest of Design Life (RDL) as follows:

$$RDL = \frac{\text{Standard CESA Accumulation}}{\text{Overloading CESA Accumulation}} \times DL$$

2.3. Serviceability
Serviceability can be calculated under some circumstances. These circumstances are the construction of the pavement has been completed, the traffic on the road has been achieved, and the traffic on the road has begun to be opened. Over time, the road serviceability will be reduced. The reduced serviceability depends on routine pavement maintenance [18].

2.4. Speed
Speed is a level of movement of vehicles or traffic expressed in kilometers per hour. The level of traffic density influences the speed and travel time of traveling from one place to the destination. By increasing the volume of traffic on the road, the level of comfort, safety, and smoothness when passing traffic will be affected. Therefore, an evaluation of the traffic condition needs to be carried out in order to maintain the level of smoothness of a road [6].
2.5. Equivalent Number of Vehicle Loads (E)

An equivalent number is a number that states the ratio of the level of damage to the pavement caused by a single axle vehicle load trajectory by a single standard load path of 8.16 tons, [15]. The equation used to determine the equivalent number of vehicles is as follows:

\[
ESA_4 = \frac{L_1}{S_{IL}} \left( \frac{\text{Single axle load (kg)}}{8160} \right)^4
\]

(2)

\[
ESA_4 = 0.086 \left( \frac{\text{Double axle load (kg)}}{8160} \right)^4
\]

(3)

\[
ESA_4 = 0.086 \left( \frac{\text{Triple axle load (kg)}}{8160} \right)^4
\]

(4)

\[
ESA_4 = 0.086 \left( \frac{\text{Quadruple axle load (kg)}}{8160} \right)^4
\]

(5)

2.6. Traffic Load

Traffic load can be calculated based on the equivalent number of the standard axle load. [15] The accumulation of traffic axle loads during the design life can be determined by the following CESA (Cumulative Equivalent Standard Axle) formula:

\[
ESA = \sum_{\text{Traktor--Trailer}} ADT \times ESA_4 \times DL
\]

(6)

\[
CESA_4 = 365 \times ESA \times R
\]

(7)

\[
CESA_5 = CESA_4 \times TM
\]

(8)

When :

- CESA = Cumulative Equivalent Standard Axle
- ADT = Average Daily Traffic
- DL = Lane Distribution
- 365 = Number of days in a year
- R = Multiplier of traffic growth
- TM = Traffic Multiplier

2.7. Pavement Thickness

The thickness of each pavement material for each surface layer, the base course layer, and the subbase course layer can be determined by the following table [15].

| Pavement Structure | Design | ESA (million) in 20 years |
|--------------------|--------|--------------------------|
|                    |        | (rank 4 unless otherwise specified) |
| Rigid Pavement with heavy traffic (CBR ≥ 2.5%) | 4   | 2 |
| Rigid Pavement with low traffic | 4A | - |
| AC WC modification or SMA modification with CTB (ESA rank 5) | 3 | 2 |
| AC with CTB (ESA rank 5) | 3 | 2 |
| AC thick ≥100 mm with granular fondation (ESA rank 5) | 3A | 2 |
| AC or HRS thin with granular fondation | 3 | - |
| Burda or Burtu with LPA kelas A | 5 | - |
| Soil Cement | 6 | - |
| Unsurfaced | 7 | - |
| Commulative Equivalent | FFF3 | FFF4 | FFF5 | FFF6 | FFF7 | FFF8 |
|------------------------|------|------|------|------|------|------|
| Single Axle for 20 years design ($10^5$ ESA5) | >4–7 | >7–10 | >10–20 | >20–30 | >30–50 | >50–100 |
| PAVEMENT LAYER THICKNESS (mm) | | | | | | |
| AC WC | 40 | 40 | 40 | 40 | 40 | 40 |
| AC BC | 60 | 60 | 60 | 60 | 60 | 60 |
| AC Base | 80 | 105 | 145 | 160 | 180 | 210 |
| LPA Kelas A | 300 | 300 | 300 | 300 | 300 | 300 |

3. Research Method

3.1. The Step of Research

In this step, the arrangement of planning and observing on the preliminary stage will be carried out in order to obtain the general description of the problems in the field. The preparation stage carried out in this study is shown in Figure 1.

![Figure 1. Chart of Research Flow](chart.png)
3.2. Research Location
The research location is on Solo-Yogyakarta KM 9-15 Road, Sleman. This road is a national road that connects two provinces, namely the provinces of Yogyakarta and Central Java.

![Figure 2. Research Location](image)

3.3. Data Collection Technique
In analyzing the effect of overloading on the design life of road in the Yogyakarta – Solo KM 9-15, primary and secondary data are required. The primary data came from the field observation and the secondary data obtained from related agencies. The technique of data collection in this study was by finding the primary and secondary information that will be used as data processing material.

3.4. Primary Data
The primary data were obtained directly in the research location both through observation or survey. The observation and survey were done through taking pictures of heavy vehicles, and conducting a survey on road surface conditions on Solo-Yogyakarta KM 9-15 Road, average daily traffic (ADT), vehicle speed, the results of weighing heavy vehicles.

3.5. Secondary Data
The data were obtained from indirect research at related agencies such as National Road Planning and Supervision Service of the Province of Yogyakarta Special Region and the Transportation Service of the Special Province of Yogyakarta. The secondary data were data on violation of overloading that occurred on Solo-Yogyakarta KM 9-15 Road. Average daily traffic data from 2014 to 2018.

4. Result and Discussion
4.1. Overloading Data
Based on the data collection and the result of a survey conducted at Weighbridge and Department of Transportation, it was obtained the data on violation number for an excessive load of the vehicle occurred at both weighbridge in Solo-Yogyakarta KM 9-15 Road in 2015. The number of violating vehicles and vehicles that do not violate every month and the total violations that occurred within one year on the Kalitirto and Tamanmartani Weighbridges are shown in Table 3.
Figure 3. Overloading Heavy Vehicle that cross the Solo-Yogyakarta KM 9-15 Road

Table 3. The number of overloading violations on Kalitirto and Tamanmartani Weighbridge in 2015 [19]

| Month   | Kalitirto | Tamanmartani |
|---------|-----------|--------------|
|         | The number of Vehicles | Violating Vehicle | The number of Vehicles | Violating Vehicle |
| January | 18475     | 2979         | 15496         | 19221         |
| February| 16919     | 2789         | 14130         | 17905         |
| March   | 18798     | 3095         | 15703         | 19788         |
| April   | 19144     | 3123         | 16021         | 18499         |
| May     | 20224     | 3233         | 16991         | 19867         |
| June    | 19789     | 3306         | 16483         | 19614         |
| July    | 10085     | 1757         | 8328          | 10132         |
| August  | 19341     | 3233         | 16220         | 19335         |
| September| 18942    | 3232         | 15710         | 19867         |
| October | 20577     | 3512         | 17065         | 21165         |
| November| 19194     | 3340         | 15854         | 20301         |
| December| 17515     | 2857         | 14658         | 19001         |
| Total   | 219003    | 36344        | 182659        | 224696        |

Source: DIY Transportation Agency for Land Transportation, 2015

Based on the recapitulation of overloading violations on Kalitirto and Tamanmartani Weighbridges, it can be seen that the number of overloading violations at Tamantani weighbridge is higher than at Kalitirto weighbridge.

The total number of vehicles that violated overloading that passed through the Kalitirto Weighbridge were 36,344 vehicles while those passing through the Tamanmartani Weighbridge were 39,550 vehicles. It means, the number of overloading vehicles that passed through Solo-Yogyakarta KM 9-15 Road which going to Solo were more significant than the vehicles went to Yogyakarta.

Table 4. Number of Violations for Each JBI Group on the Kalitirto and Tamanmartani Weighbridges [19]

| No. | Group | Weighbridge          |
|-----|-------|----------------------|
|     |       | Kalitirto | Tamanmartani |
| 1.  | Group I | 8650      | 11780        |
| 2.  | Group II| 13723     | 13894        |
| 3.  | Group III| 6992      | 7302         |
| 4.  | Group IV| 5564      | 5871         |

Source: Dishub DIY Bidang Angkutan Darat, 2015
From the data recapitulation of overloading violations occurred on Kalitrto and Tamammartani Weighbridge, it can be seen the number of violations for each class of JBI (weight allowed). The total number of vehicles violating each JBI can be seen in Table 5. Whereas based on the results of the load survey that has been carried out in the Weighbridges, the average overloading is obtained in Table 5 as follows:

Table 5. Average Overloading of Each JBI Group

| No. | JBI Vehicles | Overloading Average | Overloading Vehicles |
|-----|--------------|---------------------|---------------------|
| 1.  | JBI < 8 ton   | 2220 kg             | 24%                 |
| 2.  | 8-ton ≤ JBI ≤ 14 ton | 5079 kg | 31%                 |
| 3.  | 14 ton < JBI ≤ 21 ton | 14788 kg | 35%                 |
| 4.  | 21 ton < JBI ≤ 28 ton | 17118 kg | 39%                 |

4.2. Traffic Growth (i)

The traffic growth estimation in Road internode Solo – Yogyakarta KM 9-15 was based on the total number of traffic volume which passing that highway every year starting from 2014 to 2018. These data were obtained from DIY National Road Planning and Supervision Office. The way to determine the traffic growth figures is done by using two methods, i.e., the Exponential Method and Linear Regression Method. Based on the result of the calculation of traffic growth figures by using the exponential method, it was obtained 8.26%. Meanwhile, based on the calculation by using the linear regression method, the traffic growth figure was 7.5%. From these two methods, the traffic growth figure that used was 7.5% from the linear regression method. The method of linear regression seems to be more accurate compared to the exponential method.

4.3. The Value of CESA of standard load and CESA of Overloading

The load caused by traffic can be calculated based on the equivalent method toward a load of standard axle and overloading. To determine the accumulation of traffic axle load during the design life, CESA4 (Cumulative Equivalent Standard Axle) formula can be used in equation 7. The result of the calculation of CESA4 for standard load and overloading can be seen in Table 6 and Table 7 as follows.

Table 6. The CESA4 Value for Standard Load

| JBI  | Types of Vehicle  | ADT 2018 | ESA4 | ESA | CESA4  |
|------|-------------------|----------|------|-----|--------|
| I    | Cars              | 33,977   | 0.00045 | 7,645 | 56.207,531 |
| I    | Non Bus           | 282      | 0.01762 | 2,484 | 18.262,852  |
| I    | Pick up, box cars | 2,097    | 0.0069  | 7,235 | 53.193,131  |
| I    | Bus               | 378      | 0.05937 | 11,221 | 82.498,980 |
| II   | Large Bus         | 694      | 0.0439  | 15,233 | 111.995,986 |
| III  | Truck 2 Axle      | 1,702    | 0.7345  | 625,060 | 45.95,563,007 |
| IV   | Truck 3 Axle      | 809      | 0.6438  | 260,417 | 1.914,636,565 |
| IV   | Truck semi trailer| 68       | 0.5465  | 18,581 | 136.611,135 |
| IV   | Trailer           | 79       | 1.7493  | 69,097 | 508.014,618 |

Total 7,476,983,805

The TM value used to calculate CESA₅ is 2. The result of the calculation of CESA5 for standard load and overloading with the design life of 20 years can be seen in Table 8 as follows.
Table 7. The CESA₄ Value for Overloading

| Gol. JBI | Types of Vehicle | ADT 2018 | ADT* 2018 | ESA₄ | ESA | CESA₄ |
|---------|------------------|----------|-----------|------|-----|-------|
| I       | Cars             | 33.977   | 100       | 0.00045 | 7,645 | 56.207,531 |
| I       | Non Bus          | 282      | 100       | 0.01762 | 2,484 | 18.262,852 |
| I       | Pick up, box cars | 2.097   | 27.5    | 0.0490 | 14,129 | 103879,163 |
| I       | Bus              | 378      | 100       | 0.05937 | 11,221 | 82.498,980 |
| II      | Large Bus        | 694      | 100       | 0.04390 | 15,233 | 111.995,986 |
| III     | Truck 2 Axle     | 1.702    | 19.4     | 0.04917 | 14,129 | 103879,163 |
| IV      | Truck 3 Axle     | 809      | 15.5     | 0.05937 | 11,221 | 82.498,980 |
| IV      | Truck semi trailer | 68         | 15.5     | 0.05937 | 11,221 | 82.498,980 |
| IV      | Trailer          | 79       | 100      | 0.05937 | 11,221 | 82.498,980 |
|         |                  |          |          |       |     | Total 18.491.035,103 |

Table 8. the Value of CESA₅ of Standard Load and CESA₅ of Overloading

| CES₅ of standard load (CESA₄ x TM) | CES₅ of Overloading |
|-----------------------------------|---------------------|
| 14.9 × 10^6                      | 36.9 × 10^6         |

4.4. The Decrease of Design Life

Based on the result of the calculation of standard load and overloading CESA above, it can be seen that the value of overloading CESA is more significant than the value of standard load CESA. This phenomenon that affects the service life on road pavement. To determine the rest of design life can be used the equation 1. From the calculation of the rest of design life for projection life of 20 years, it can be obtained the rest of the design life was eight years, and the decrease of design life was 12 years.

4.5. The Effect of Load on the Pavement Thickness Performance

Based on the result of the analysis on the decreasing of design life was caused by the overloading on Solo-Yogyakarta KM 9-15 Road, it was known that there was a decrease of design life from the design life that has been determined before. The analysis of the effect of the load against pavement thickness performance aims to know the pavement thickness performance that was caused by the average load and overloading. Table 1 is used to determine which number of pavement designs are appropriate. The type of pavement design is 3A. Pavement thickness is determined by plotting the CESA₅ value in the Table 10 for standard load and overloading.

The analysis of pavement layer thickness due to the standard load and overloading by using the method of Binamarga 2013, it can be obtained the pavement layer thickness with a standard load for surface layer are 40 mm for ACWC and 60 mm for AC BC, the base course layer is 145 mm, and the subbase course layer is 300 mm. At the same time, for overloading, it can be obtained the surface layer are 40 mm for ACWC and 60 mm for AC BC, the base course layer is 180 mm, and the subbase course layer is 300 mm. The comparison can be observed in Figure 4.
Table 9. Pavement Layer Thickness for Standard Load and Overloading[15]

|                | FFF3 | FFF4 | FFF5 | FFF6 | FFF7 | FFF8 |
|----------------|------|------|------|------|------|------|
| Commulative Equivalent Single Axle for 20 years design (10⁶ ESA5) |      |      |      |      |      |      |
| >4–7           |      |      |      |      |      |      |
| >7–10          |      |      |      |      |      |      |
| >10–20         |      |      |      |      |      |      |
| >20–30         |      |      |      |      |      |      |
| >30–50         |      |      |      |      |      |      |
| >50–100        |      |      |      |      |      |      |

PAVEMENT LAYER THICKNESS (mm)

|                | AC WC | AC BC | AC Base | LPA Kelas A |
|----------------|-------|-------|---------|-------------|
| Standard load  | 40    | 60    | 80      | 300         |
| Overloading     | 40    | 60    | 145     | 300         |
|                 | 40    | 60    | 160     | 300         |
|                 | 40    | 60    | 180     | 300         |
|                 | 40    | 60    | 210     | 300         |

Figure 4. The Pavement Layer Arrangement due to the Impose of Standard Load and Overloading based on Binamarga Method.

5. Conclusion

Based on the result of the data analysis and the discussion on the effect of overloading and pavement thickness that have been carried out, then it can be concluded as follows:

a. From the calculation of CESA₅ value, it can be obtained the figure of CESA₅ Binamarga 2013 Method for a standard load of 14.9 × 10⁶ ESAL and the figure of CESA₅ for overloading, i.e., 36.9 × 10⁶ ESAL. From these calculations, there was a quite significant difference between the value of CESA₅ for the standard load and overloading. This phenomenon will decrease the design life of road pavement on Solo-Yogyakarta KM 9-15 Road.

b. Based on the analysis on the decrease of design life, it was obtained that the rest of design life for Binamarga 2002 Method was 8 years from the design life that had been determined before, i.e., 20 years.

c. From the result of the calculation of pavement thickness for standard load and overloading, it can be obtained that the pavement thickness of Solo-Yogyakarta KM 9-15 Road at the design life of 20 years as follows:

- Due to the standard load, the thickness of the pavement for the standard load at the surface layer was 100 mm consist of AC WC 40mm and AC BC 60mm, base course layer was 145mm, and subbase course layer was 300 mm.
- Due to the overloading, the thickness of the pavement layer with overloading found that the thickness of the pavement layer for the surface layer was 100 mm consist of AC WC 40mm and AC BC 60mm, base course layer was 180mm, and subbase course layer was 300 mm.
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