The Influence of Overloading Truck to the Road Condition

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Abstract. Traffic load is dominant function on pavement design because the main function of pavement is to resist traffic load. Efforts to repair of the road damages have been done; but almost meaningless since the overloading trucks keep in progress, even reach twofold from the normal load. Analysis of sensitivity was used to measure the influence of overloading to level of road damage. In addition of analysis of sensitivity, calculation using vehicle damage factors (VDF) was also used to determine the capacity of single, dual, or triple axle trucks on damaging of pavement. The result of analysis of sensitivity show that 150% overloading of single, dual, and triple axle truck, will bring about 500, 135, and 122% level of damage respectively. The results of calculation using VDF also have the similar result namely 47.20, 10.30, and 7.99 times the capacity to deteriorated pavement respectively.

Keywords: Overloading, axle-truck, road, pavement, damage

1. INTRODUCTION

The condition of many roads in Indonesia, both, National, Province, and District roads are damages in early stages of its service life. The main factor causing those early damages is overloading trucks, since the most significant load applied to a pavement surface comes from a truck (Rajib, B.M. and Tahar El-Korchi, 2009).

Efforts to repair of the road damages have been done by Directorate General of Bina Marga (the Directorate General of Highways (DGH), Ministry of Public Works Republic of Indonesia). However, all efforts to repair the road condition, even though conducted by using suitable pavement materials and also constructed in the proper way, have meaningless since the truck loads which was used as criteria for designing pavement structure, is uncontrolled and overload. DGH data, found by using weigh-in-motion (WIM) system and given graphically in Figure 1a and 1b, show that the actual truck axle load in segment road Semarang – Jakarta and Semarang – Surabaya, is twofold than allowable axle load. (Source: DGH).

The high number of those overloading is due to absence of local (provincial) government support. They use weighing bridge not to control truck load, by reducing the load if excess, but to collect an income, by charging fee to the overload truck instead of demolish and reduce the load. The absence of provincial government support is appearing from the agreement of 8 Province Traffic and Land Transportation Officials (Dinas Lalu-Lintas dan Angkutan Jalan Raya or DLLAJR). In Bandung, the eight of DLLAJR of Provincial Government consist of Lampung, Banten, Jakarta, West Java, Central Java, Jogjakarta, East Java, and Bali Province; on April 26, 2006 have made an agreement to give tolerance of overload truck up to 70%. This mean that trucks are allowed to carry the load 70% more than allowable load, and actually the load is 200% higher than allowed, not only 70%, because of the policy in the weighing bridge.

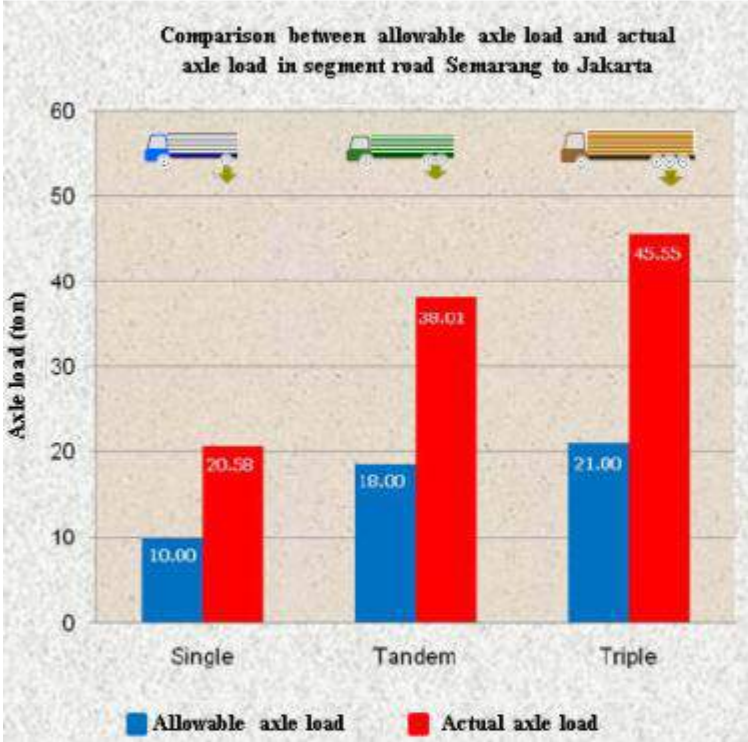


Figure 1a. Comparison between allowable and actual axle load in segment road Semarang – Jakarta (Source: DGH)

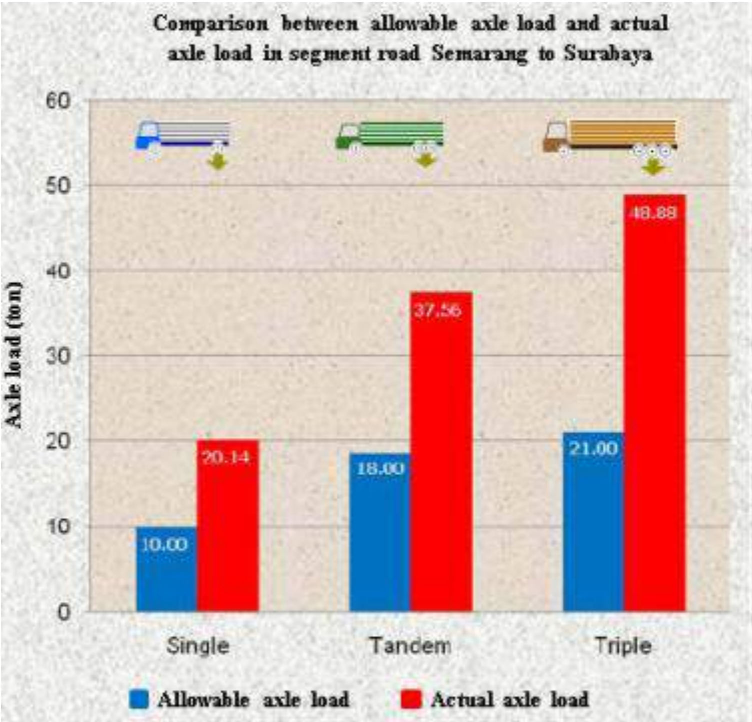


Figure 1b. Comparison between allowable and actual axle load in segment road Semarang – Surabaya (Source: DGH)

2. PROBLEM

Although is not the only one, truck load is dominant factor responsible for road damage, because pavement are designed to resist traffic load, especially truck load. The problem which will be discussed in this paper is much of overloading trucks in Indonesia that as shown in Table 1 and also in Figure 1a and 1b, the overloading is reach more than 200%. These overloading have worst impact to the road condition and in turn to the national economy.

Table 1. Overloading truck in the road Jakarta – Semarang – Surabaya [Source: DGH)

Type of truck axle	Semarang - Jakarta				Semarang - Surabaya			
	ADT	Legal axel limit	Actual load (ton)	% Overloading	ADT	Legal axel limit	Actual load (ton)	% Overloading
Single axle	3.389	10.00	20.58	205.80	1.365	10.00	20.14	201.40
Double axle	1.14	18.00	38.01	211.17	1.07	18.00	37.56	208.67
Triple axle	352	21.00	45.55	216.90	384	21.00	48.88	232.76

Note: ADT = Average Daily Traffic

3. OBJECTIVE OF THE PAPER

The objective of the paper is to study the influence of overloading trucks to the strength of materials of pavement layers and other factors causing the pavement damage, like tyre pressure, environment, type of axle of the truck.

4. RESEARCH METHODOLOGY

The methodology use in this research is by describing the factors which affected the road damages. Those factors, traffic load, stress at the surface layer cause by excessive of tyre pressure, pavement materials, pavement layers thickness, roadbed or subgrade soil, and environment then to be analyzed by using analysis of sensitivity. In addition of analysis of sensitivity, calculation using the vehicle damage factor (VDF) was also used to measure the influence the number of truck axle. First of all, factors which affected the road damage will be described.

5. FACTORS AFFECTED THE ROAD DAMAGE

Overloading is very often assumed as the factor that affects the level of pavement structure damage. Even though that assumption is not wrong but the other factors need to be thoroughly and proportionally studied before take the conclusion. Generally factors that influence the road damage can be described as follows:

5.1 Traffic load (overloading of the heavy vehicle or truck and frequency of the traffic).
5.2 Stress on the surface layer of the pavement (cause by higher tyre pressure which account for the higher stress on surface layer)
5.3 Characteristic of pavement materials (their quality that expressed as number of relative strength)
5.4 Thickness layers factor
5.5 Subgrade or roadbed soil (the bearing capacity of soil)
5.6 Regional or environment factor
5.7 Failure criterion

Those five factors are described as follows:

5.1 Traffic load

Traffic load is dominant function because the function of the pavement is to directly resist the traffic load. The mention of traffic load covers traffic volume or frequency of the traffic, and weight of vehicle as well as intensity of the vehicle. Traffic volume accumulatively shows the number of repetition of the load and function the time (service life). Intensity of the weight of vehicle is depending on weight of axle load, axle configuration, and wheel configuration.

In the Empiric Method, the method to calculate flexible pavement thickness use by DGH, (SKBI 2.3.26), traffic load is expressed as Equivalent Design Wheel Path (Lintas Ekivalen Rencana) in this paper denote as LER or accumulatively during premeditated service life, and expressed as cumulative of LER denote as N, where:

$$N = 365\ x\ LER\ (1+g)(1+g)^n/i \quad (1)$$

$$LER = [(\sum LHR_{0i}\ x\ AE_i\ x\ C_i\ x\ D_i) + (\sum LHR_{ni}\ x\ AE_i\ x\ C_i\ x\ D_i)]/2 \quad (2)$$

where:

N = Cumulative Equivalent Design Wheel Path during service life period
LER = Equivalent Design Wheel Path
LHR = Average Daily Traffic
AE = Equivalent of Axle Number = $\delta\ (BS/8.16)^2$
C = Coefficient of Lane Distribution
D = Coefficient of Direction Distribution
g = Traffic Growth Factor per Annum in %
Subscript o = initial of design life;
Subscript n = end of design life;
Subscript i = type of vehicle
δ = 1 for single axle; 0.086 for dual axle, and 0.053 for triple axle
BS = Standard axle load, equal to 8.154 ton.

From the equation (1) and (2) above, could be understood that the higher of traffic volume, the higher level of road damage will be, or the higher axle load, the higher level of road damage will be.

5.2 Stress on surface pavement cause by tyre pressure

Tyre pressure is remarkably influence the stress to the surface layer of pavement under tyre contact area. The higher of tyre pressure, the higher the stress on surface layer of the pavement.

The relation between tyre pressures and the stress in surface pavement is expressed as the relation between Marshall Stability (MS) of surface layer material and Unconfined Compression Strength (UCS) which based on Indra Surya (Indra Surya, 1999) is as follows:

UCS_{AC} = 0.0084 x MS (kg) → for asphaltic concrete
UCS_{HRS} = 0.0091 x MS (kg) → for Hot Rolled Asphalt
UCS_{ATB} = 0.0088 x MS (kg) → for Asphalt Treated Base

The relation between Marshall Stability (MS) and tyre pressure (p_o) is: MS (kg) = 10 p_o (psi), with assumption that the strain strength factor (SF) is determination factor.

5.3 Characteristic of pavement layers materials

Characteristic of pavement layers materials (strength, stiffness, elasticity) extremely influential to the performance of pavement layers to response the traffic load. The higher quality of the materials, the higher the ability to response the load will be. The ability of pavement layers materials to response traffic load is expressed by Coefficient of Relative Strength a_i = f (MS) for surface layer, and a_i = f (CBR) for base and sub-base layer.

Bandung Institute of Technology has developed the equation to calculate the coefficient of relative strength for each layer or materials from DGH's Empiric (SKBI 2.3.26) Method as follows:

$$a_1 = -3.72\ x\ 10^{-0.8} MS^2 + 3.04\ x\ 10^{-0.4} MS + 0.20 \quad (3)$$
→ for asphalt concrete layer
$$a_2 = -1.43\ x\ 10^{-0.2}\ (\log CBR)^2 - 1.00\ x\ 10^{-0.1}\ (\log CBR) + 0.15 \quad (4)$$
→ for base layer
$$a_3 = -7.40\ x\ 10^{-0.3}\ (\log CBR)^2 - 9.68\ x\ 10^{-0.3}\ (\log CBR) + 0.08 \quad (5)$$
→ for sub-base layer

5.4 Thickness layers factor

Improperly of pavement structure construction often cause the layer thickness are not fulfill the thickness as required in the design specification. The thickness of one layer unquestionably will influence performance of entirely pavement structure. The thicker of the pavement layer over the design requirement, the higher the performance of the pavement to response traffic loading will be.

Layer thickness is expressed in D_1, D_2, and D_3 for surface, base, and sub-base layer respectively. The effect of change in the layer thickness is similar to the effect of change in the quality of the pavement materials.

5.5 Roadbed soil or sub-grade characteristic

Change of the properties of road-bed soil is extremely affecting the performance of pavement structure. The smaller of ability or the smaller of bearing capacity of existing road-bed soil, the weaker ability of pavement to response traffic loading, and on the contrary. The strength or bearing capacity of road-bed soil is expressed in CBR value or in bearing capacity of soil (BCS). The equation to calculate bearing capacity is as follows:

$$BCS_r = BC_{avg}^2 + \beta\sigma \quad (6)$$

$$BCS_i = 4.30\ logCBR + 1.70 \quad \text{(Based on Indra Surya} \quad (7)$$

$$BCS_i = 3.71\ logCBR + 1.35 \quad \text{(Based on AASHTO 1986)} \quad (8)$$

where:

β = 2.00 (for level of confidence 98%)
  = 1.67 (for level of confidence 95%)
  = 1.28 (for level of confidence 90%)
σ = Standard deviation of CBR value

5.6 Regional or environment factors

Condition of road-bed soil is extremely influence by environment condition that specifically is influenced by change in water content. Such as the graph in relation between water content and density, the highest or the lowest of water content from the optimum condition, the smaller of the bearing capacity. This condition is not only occurring in road-bed soil but also in base and sub-base layer.

5.7 Failure criterion

Parameter of failure criterion use in this paper is permanent deformation or rutting. Rutting is the signal of pavement failure as a result of excessive of the fatigue strain on asphalt surface pavement or because of excessive of vertical compressive stress on the top of base, sub-base, and of roadbed soil layer. Beside expressed in fatigue strain (ε) and vertical compressive stress (σ) as mentioned above, rutting is also expressed in parameter of Present Serviceability Index (PSI) that a function the level of road deterioration in form level of cracking, pothole, and the depth of the path of permanent deformation. Equation for calculating of PSI according ASSHTO (William, D.O.) is:

$$PSI = 5.03 - 1.91\ log_{10}\ (1 + SV) - 1.38\ RD^2 - 0.01\ (C + P)^{0.5} \quad (9)$$

where:

PSI = Present Serviceability Index
SV = Slope of Variance, a measure of longitudinal roughness;
C + P = Area of class 2 and class 3 cracking* plus patching, in ft/1,000 ft^2 (or tenths of a percent).
* = Cracks of 1 to 3 mm width, and more than 3 mm width, respectively.
RD = Average Ruth Depth, in inches

6. INDEX OF PAVEMENT THICKNESS (IPT)

Index of pavement thickness (IPT) is dependent variable to determine the pavement layers thickness and to show the performance of the layer of pavement structure that is affected by that independent variable namely traffic and it load intensity, quality and thickness of pavement layers, roadbed soil environment factor, as well as fatigue criterion. Those relations mathematically can be expressed as follows:

$$\log(LER\ x\ 365) - 9.36\log(IPT/2.54 + 1.0) - 0.20 + \frac{\log[(IPo - IPt)/(4.20-1.50)]}{\left[0.40 + 1094/\left\{\left(\frac{IPT}{2.54}+1\right)^{5.10}\right\}\right]} + \log(1/FR) + 0.372\ (BCS - 3.0) \quad (10)$$

where:

LER $= (LEP + LEA)/2$
LEP $= \Sigma\ LHR_{01}\ x\ AE_i\ x\ C_i\ x\ D$
LEA $= \Sigma\ LHR_{ni}\ x\ AE_i\ x\ C_i\ x\ D_i$
LHR_{ni} $= LHR_{01}n(1 + r_i)^2$
IP $= 5.03 - 1.9 \log(1 + SV) - 0.01\ (C + P)^{0.5} - 1.38\ RD^2$
BCS $= 4.30 \log(CBR) + 1.70$
IPT $= \Sigma a_i\ x\ D_i - (a_1 + D_1) + (a_2 + D_2) + (a_3 + D_3)$

7. ANALYSIS OF SENSITIVITY

Besides using the above equation, the level of road damage can also be approached by function and relation of variables that can be expressed as follows:

$$f_K = f\ (AE, Vol, psi/MS\ , a_iD_i, BCS, FR\ ) \quad (11)$$

where:

f_K = level of road damage
AE = rate of equivalent (level of damage cause by axle load)
Vol. = traffic volume
psi = tyre pressure
MS = Marshall Stability (level of quality of asphalt surface layer)
a_i = rate of relative strength (quality of pavement layer materials)
D_i = thickness of pavement layers
BCS = bearing capacity of soil

Modeling of road damage is very difficult to be conducted here, since there are not enough data and there is no sufficiently observation of empiric-historic to the pavement. Therefore, one can be conducted is using analysis of sensitivity to measure the percentage contribution of each variable to the pavement damage. This analysis is carried out by using nine variables. The percentage contribution of those nine variables to the road damage can be determined from the analysis. Those nine variables are:

1. Quality and thickness of surface pavement, denote as relative of layer strength $a_,$ and determine the percentage contribution of surface pavement to damage.

2. Quality and thickness of base layer denote as relative layer strength a_2, and determine the percentage contribution of base layer to damage.
3. Quality and thickness of sub-base layer denote as relative layer strength a_3, and determine the percentage contribution of sub-base layer to damage.
4. Overloading of single axle truck denote as single axle load structural number N_{st}, and determine the percentage contribution of single axle to damage.
5. Overloading of dual axle truck denote as dual axle load structural number N_{sg}, and determine the percentage contribution of dual axle to damage.
6. Overloading of triple axle truck denote as triple axle load structural number N_{tr}, and determine the percentage contribution of triple axle to damage.
7. Overstress of tyre pressure denote as psi, and determine the percentage contribution of tyre pressure to damage.
8. Reduction of bearing capacity of roadbed soil denotes as BCS, and determines the percentage contribution of roadbed soil to damage.
9. Regional/Environment factor denote as FR, and determine the percentage contribution of regional/environment factor to damage.

By using 100% as the rate for normal condition of the pavement (show in the row % variable 100 in Table 2), the percentage contribution of road damage of each variable is known. The impact of increasing axle load and overloading to the damage variables are given graphically in Figure 2 as well as show in Table 2. To make analysis of sensitivity clear, variables that cause the road damages are shown in Appendix A, chart of analysis of sensitivity. This chart is making based on the equation (11). In Appendix B are given some pictures of overloaded trucks.

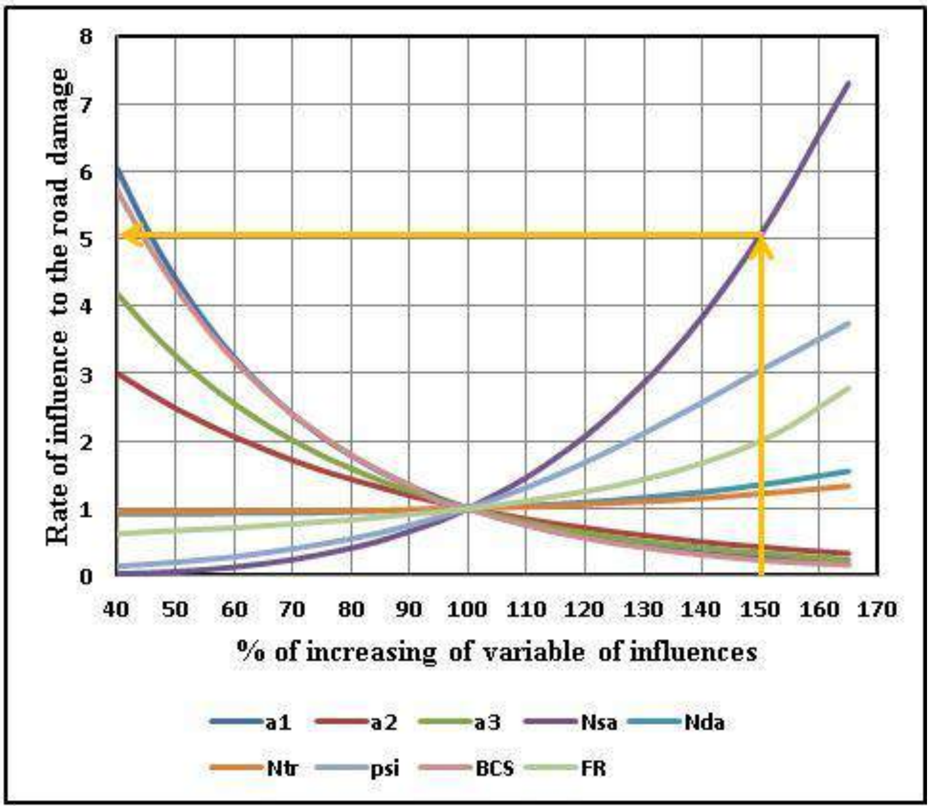


Figure 2. Chart variable of analysis of sensitivity

Table 2. Variables of Analysis of Sensitivity

Axle load	Variable of analysis of sensitivity								
	Surface	Base	Subbase	Single	Dual	Triple	Tyre pressure	Subgrade	Reg. Factor
%	a1	a2	a3	Nsa	Nda	Ntr	psi	BCS	FR
40	6.03	3.00	4.18	0.03	0.92	0.95	0.14	5.71	0.62
45	5.15	2.73	3.69	0.04	0.92	0.95	0.17	4.94	0.65
50	4.4	2.48	3.26	0.06	0.92	0.95	0.20	4.27	0.67
55	3.77	2.26	2.88	0.09	0.92	0.95	0.24	3.69	0.69
60	3.23	2.06	2.55	0.13	0.93	0.95	0.28	3.19	0.71
65	2.78	1.88	2.26	0.18	0.93	0.96	0.34	2.76	0.74
70	2.39	1.71	2.01	0.24	0.93	0.96	0.40	2.39	0.77
75	2.06	1.56	1.78	0.32	0.94	0.96	0.47	2.07	0.80
80	1.78	1.43	1.59	0.41	0.95	0.97	0.55	1.79	0.83
85	1.54	1.31	1.41	0.52	0.96	0.97	0.64	1.55	0.87
90	1.33	1.19	1.26	0.66	0.97	0.98	0.75	1.34	0.91
95	1.15	1.09	1.12	0.81	0.98	0.99	0.87	1.10	0.95
100	1.00	1.00	1.00	**1.00**	1.00	1.00	1.00	1.00	1.00
105	0.87	0.92	0.89	1.22	1.02	1.01	1.15	0.86	1.05
110	0.76	0.84	0.80	1.46	1.04	1.02	1.31	0.75	1.11
115	0.65	0.77	0.71	1.75	1.06	1.04	1.49	0.65	1.18
120	0.58	0.71	0.64	2.07	1.09	1.06	1.68	0.56	1.25
125	0.50	0.65	0.57	2.44	1.12	1.08	1.89	0.48	1.33
130	0.44	0.60	0.51	2.86	1.16	1.10	2.11	0.42	1.43
135	0.39	0.55	0.46	3.32	1.20	1.12	2.34	0.36	1.54
140	0.34	0.50	0.42	3.84	1.24	1.15	2.57	0.31	1.67
145	0.30	0.46	0.37	4.42	1.29	1.18	2.81	0.27	1.82
150	0.28	0.43	0.34	**5.06**	1.35	1.22	3.05	0.23	2.00
155	0.23	0.39	0.30	5.77	1.41	1.25	3.28	0.20	2.22
160	0.20	0.36	0.27	6.55	1.48	1.29	3.51	0.18	2.50
165	0.17	0.33	0.24	7.30	1.55	1.33	3.74	0.16	2.78

Note: **The row of axle load 100% is normal load and normal condition**
The row of axle load 150% is the variables condition cause by 150% of overloading

8. RELEVANCY OF FACTORS AFFECTED THE ROAD DAMAGE, INDEX OF PAVEMENT THICKNESS (IPT), AND ANALYSIS OF SENSITIVITY

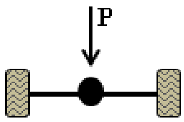
Pavement structure damage as mentioned in section 4 is caused by overloading, high tyre pressure, quality of pavement materials, pavement layer thickness, bearing capacity of subgrade soil, environment factor, and failure criterion use in designing of pavement structure. Those factors affect performance of the layer of pavement structure that measure by index of pavement thickness (IPT). The level or percentage of of those factors to damage the pavement is determined by analysis of sensitivity.

9. VEHICLE DAMAGE FACTOR (VDF)

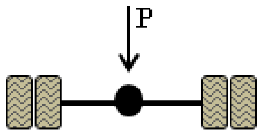
Besides using analysis of sensitivity, the influence of overloading truck to the road condition also can be shown by using vehicle damage factor (VDF). VDF is the ratio between capacities to damage by axle load of vehicle to the standard axle load. This ratio is not linear but exponential ratio (Source: DGH) and expressed as follows:

$$VDF = \left[\frac{Vehicle\ axle\ load}{Standard\ axle\ load}\right]^4$$ → 

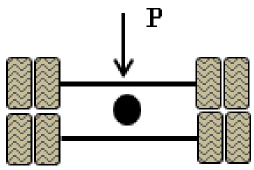
→ General equation

$$VDF = \left[\frac{P}{5.4}\right]^4$$ → 

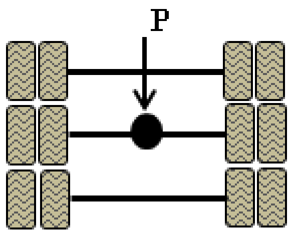
→ Front wheel

$$VDF = \left[\frac{P}{8.16}\right]^4$$ → 

→ Single axle rear wheel

$$VDF = \left[\frac{P}{15}\right]^4 = 0.086\left[\frac{P}{8.16}\right]^4$$ → 

→ Dual axle rear wheel

$$VDF = \left[\frac{P}{18}\right]^4 = 0.053\left[\frac{P}{8.16}\right]^4$$ → 

→ Triple axle rear wheel

10. EMPIRICAL STUDY OF VDF

A single axle truck have load configuration 8.549 ton of front wheel and 20.862 ton of rear wheel. The VDF for single, dual, and triple axle load calculated using the above equations is:

a. VDF of single axle : $VDF_S = \left[\frac{8.549}{5.4}\right]^4 + \left[\frac{20.852}{8.16}\right]^4 = 47.20$

b. VDF of dual axle : $VDF_D = \left[\frac{8.549}{5.4}\right]^4 + \left[\frac{20.852}{15}\right]^4 = 10.30$

c. VDF of triple axle : $VDF_T = \left[\frac{8.549}{5.4}\right]^4 + \left[\frac{20.852}{18}\right]^4 = 7.99$

From the calculation above show that: VDF for single axle truck is 4.58 times VDF for dual axle, and 5.90 times of triple axle.

If the average daily traffic (ADT) of that road is 3.389 single axle trucks per day, design life (dl) of the pavement is 10 years, and traffic growth, g = 6% per year, the influence of adding axle form single to dual and triple axle to the cumulative equivalent single axle load (CESAL) can be calculated by using the equation:

$$CESAL_{10} = (ADT\ x\ 365)\ x\ \frac{(1-g)^{dl}-1}{g}\ x\ C\ x\ D\ x\ VDF \quad (12)$$

where:

dl = design life of the pavement
g = traffic growth per year
C = Coefficient of Lane Distribution
D = Coefficient of Direction Distribution
365 = number of day during one year.

then:

$$CESAL_S = (3.389\ x\ 365)\ x\ \frac{(1-0.06)^{10}-1}{0.06}\ x\ 0.5\ x\ 1\ x\ 47.20 = 384.78\ x\ 10^6$$

$$CESAL_D = (3.389\ x\ 365)\ x\ \frac{(1-0.06)^{10}-1}{0.06}\ x\ 0.5\ x\ 1\ x\ 10.30 = 83.97\ x\ 10^6$$

$$CESAL_T = (3.389\ x\ 365)\ x\ \frac{(1-0.06)^{10}-1}{0.06}\ x\ 0.5\ x\ 1\ x\ 7.99 = 65.14\ x\ 10^6$$

$CESAL_S$ = Cumulative equivalent single axle;
$CESAL_D$ = Cumulative dual axle load; and
$CESAL_T$ = Cumulative triple axle load.

Can be seen from the calculation that using the same load, CESAL during design life decrease from 384.78 x 10^6 ESAL for single axle to 83.97 x 10^6 ESAL and 65.14 x 10^6 ESAL. These results show that detrimental effect of single axle truck is very high.

11. CASE STUDY OF ANALYSIS OF SENSITIVITY

Case study was taken from Godong – Demak road (25km East Semarang). The condition of this road was damage caused by overloaded truck. This road was designed using 8 tons Equivalent Single Axle Load (ESAL), standard load design for provincial road. Construction of the pavement was Penetration McAdam where the pavement structure consists of Penetration McAdam with 10 cm thickness as surface pavement, aggregate class B for base layer, and boulder for sub-base laid on road-bed soil which has CBR value 4%.

Many trucks with rear dual axle which have average total weight 32.5 tons passing this road resulted the pressure of each axle = (75% x 32.5)/2 tons = 12 tons or 150% above ESAL design load 8.16 tons. Based on analysis of sensitivity 150% overloaded cause the rate of relative strength for surface layer decrease from 1 to 0.28, for base layer from 1 to 0.43, and for sub-base layer decrease from 1 to 0.34. Decreasing of the rate of relative strength for all pavement layers has caused permanent deformation, and in turn total road damage occurs.

12. CONCLUSIONS

From the analysis of sensitivity and vehicle damage factor (VDF) calculation results, the conclusions can be drawn as follows:

1. The detrimental effect of single axle trucks is high compare to dual or triple axle trucks.
2. Relative strength of pavement structure cause by overloading of single axle truck decrease much more than cause by overloading of dual or triple axle truck.
3. The higher the overloading, the higher decreasing of relative strength of pavement structure.

13. RECOMMENDATION

To prevent early damage of pavement structure, some efforts are needed to be conducted:

1. Anticipation occurring of early damage on pavement structure caused by overloading truck, especially single axle truck, is needed.
2. Strict on quality control during construction period to insure that all specifications are met the requirement is required and is very important.
3. Strict control on overloading truck by controlling limited truck load is required.
4. Regulation to call for using multi-axle truck instead of single-axle truck is needed to be considered

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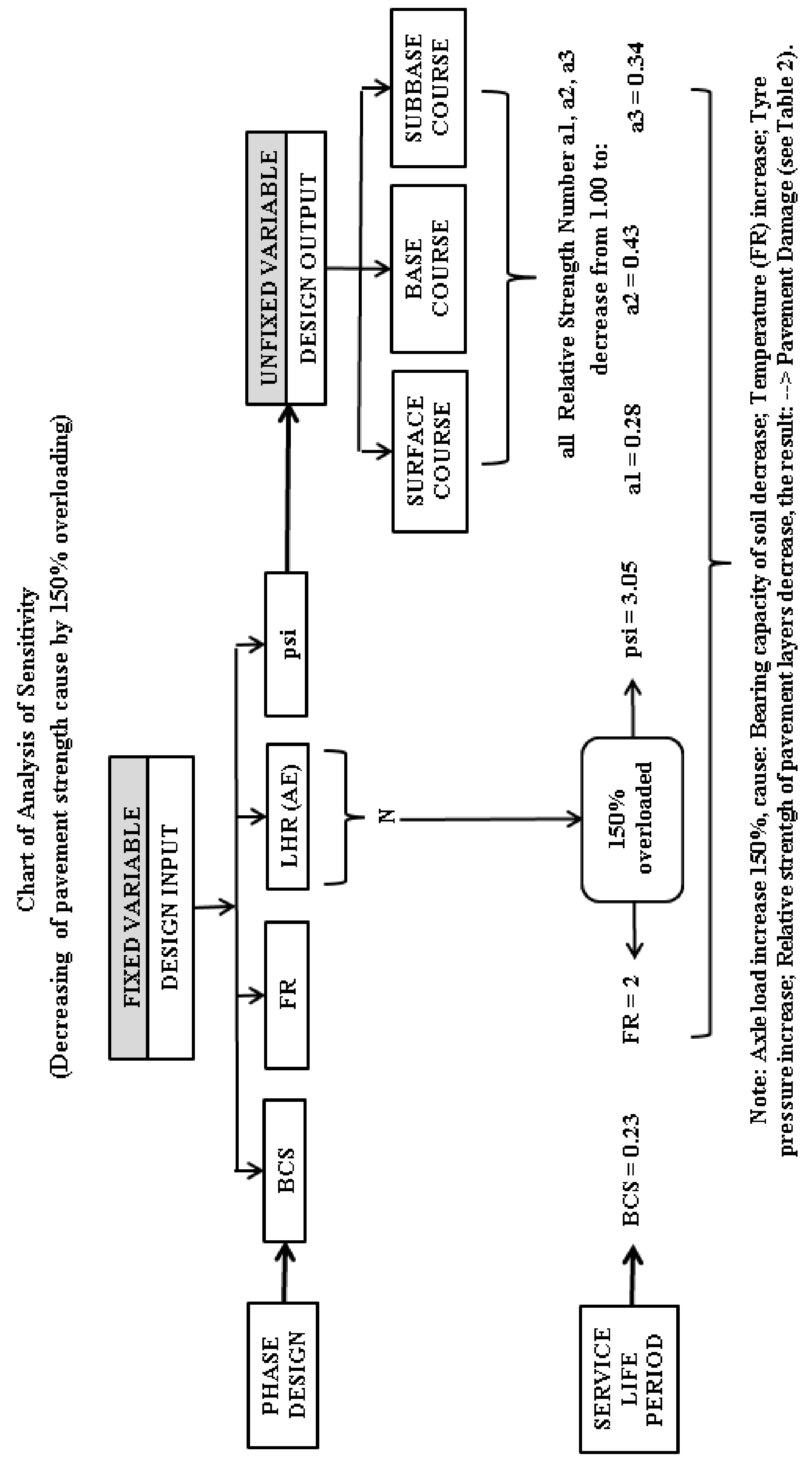
APPENDIX A

CHART OF ANALYSIS OF SENSITIVITY OF PAVEMENT TO OVERLOADING



APPENDIX B-1

PICTURES OF OVERLOADING TRUCK IN NORTH TRANS JAVA ROADS

APPENDIX B-2

PICTURES OF OVERLOADING TRUCK IN NORTH TRANS JAVA ROADS