Investigation of the correlation between drainage condition and pavement performance

D Iskandar, S P Hadiwardoyo*, R J Sumabrata and M Fricilia
Civil Engineering Department, Faculty of Engineering, Universitas Indonesia,
Kampus Depok 16424, Indonesia

*E-mail: sigit@eng.ui.ac.id

Abstract. One of pavement deterioration causes is the lack of road drainage maintenance. Road drainage system has a function to dry the pavement thus water can flow as quickly as possible out of the road surface and then flow through the channel to the final disposal. Road distress will interfere the comfort and safety ride and affect the pavement structure performance and quality. This research aims to identify and analyze the influence of drainage conditions through road pavement structures distress using Pavement Condition Index (PCI) method in Jakarta. The method used is a field research with primary data in the form of road distress survey that will be evaluated using PCI and analyzed using factorial experiment design. The research results using Design of Experiments shows that the main factors which greatly influence the road distress is drainage conditions, PCI score and surface water condition. Most of the surveyed region has a “good” PCI score and “routine maintenance” type.

1. Introduction
There are three factors affecting the quality of road, namely road construction process quality, drainage conditions and its surroundings, and excessive load on road. Overloading can cause the burden of each vehicle axle exceeding the specified standard [1,2]. Pavement distress can be caused by excessive traffic loads, unstable subgrade conditions, poor soil conditions, poor pavement structure and processing, a decline due to construction of utilities under pavement, too much asphalt, pavement fatigue, environmental conditions (temperature and high rainfall), and poor drainage [3]. Rapid pavement distress is caused by the lack maintenance of drainage system. Roads that are built without a good drainage system have a faster distress speed, thus the age of the pavement design will be shorter. Good drainage must be able to avoid road distress problems caused by weather and traffic loads. Puddles are the main problem of asphalt roads because the water collected on the surface will seep into the pores and deteriorate the asphalt bonds to the road foundation.

This study explains the correlation between drainage conditions and flexible pavement structures in several locations in Jakarta. The survey is carried out on roads with classifications of collector road and distress assessment caused only by water or exacerbated by water. Determination of drainage conditions and surface water is purely based on functional only.

Some studies on the impact of drainage conditions on the distress of flexible pavement structures have been done previously. Drainage renewal experiment conducted by Mia Muhammad NU aims to: (1) prevent moisture trapped in the road shoulder and roadway; (2) eliminate moisture on the joint surface; (3) increase the life cycle of pavement through increasing subsurface drainage; (4) reduce the premature failure risk of shear and permanent deformation due to moisture during pavement
construction; (5) prevent pumping and the effects of blistering in the surface layer, especially in plate parts or joints by lowering the groundwater level; and (6) increase the efficiency of the existing drainage role through the installation and replacement of existing pavements, subgrade and manhole [4,5].

2. Literature Review

2.1. Data Collection

This research aims to know the correlation between flexible pavement structures distress and drainage conditions. Data collection begins by surveying roads randomly with limitation criteria, namely: types of flexible pavement, collector road classes, open drainage channels, excluding bends, slopes/downhill and intersections, and low intensity of heavy vehicles on the road.

Data is collected from a visual survey of flexible pavement structures, then evaluated and categorized its drainage conditions around the area of road distress and surface water conditions after raining. Then the level of distress is measured.

The survey is conducted by observing the distress occurred on the road surface and drainage beside it. There are 32 research locations observed and spread in 5 regions in Jakarta [6]. The qualitative data obtained are analyzed using a statistical approach based on literature and assisted using statistical processing software.

2.2. Pavement Condition Index

Assessment system of pavement condition is done based on the type and level of road distress using the PCI method. Survey is conducted to identify distress occurred on pavement. The results are used to determine the distress level and then the analysis of drainage conditions impact is done. Distress identification is intended to determine the distress type, distress area and distress classification [1].

The distress type is measured its level to be referred to the literature. Further examination and assessment in surveyed location considers Table 1 as a reference for distress assessing and grouping. Measurement is carried out in the depth below the distress of the road surface and drainage. The results of monitoring and investigation of 32 locations are presented in the Table 1.

| No | PCI  | Drainage Condition | Presence of Puddles |
|----|------|---------------------|---------------------|
| 1  | 95.6 | Good                | Yes                 |
| 2  | 84   | Moderate            | Yes                 |
| 3  | 92   | Good                | Yes                 |
| 4  | 83   | Good                | Yes                 |
| 5  | 98   | Good                | Yes                 |
| 6  | 86   | Moderate            | No                  |
| 7  | 75   | Moderate            | Yes                 |
| 8  | 88   | Good                | No                  |
| 9  | 85   | Good                | Yes                 |
| 10 | 79   | Good                | Yes                 |
| 11 | 87.6 | Moderate            | Yes                 |
| 12 | 76.4 | Moderate            | Yes                 |
| 13 | 79.5 | Moderate            | No                  |
| 14 | 78   | Moderate            | No                  |
| 15 | 72.5 | Moderate            | No                  |
| 16 | 90.2 | Moderate            | Yes                 |
| 17 | 79   | Moderate            | Yes                 |
| 18 | 91   | Good                | No                  |
| 19 | 98   | Moderate            | Yes                 |
| 20 | 94   | Good                | No                  |
2.3. Rating Evaluation Road Drainage
The categorization is done based on a visual assessment according to the literature. In this case there are three evaluation categories: drainage conditions (fig. 1 and fig. 2), surface water conditions (fig. 3 and fig. 4) and damage level condition (Table 2) [7,8]. Categorization has subcategories that describe the condition of location.

| No | PCI  | Drainage Condition | Presence of Puddles |
|----|------|---------------------|---------------------|
| 21 | 85   | Good                | No                  |
| 22 | 94.2 | Good                | No                  |
| 23 | 93.9 | Good                | No                  |
| 24 | 91.7 | Moderate            | No                  |
| 25 | 85   | Good                | No                  |
| 26 | 98   | Good                | No                  |
| 27 | 90   | Good                | No                  |
| 28 | 86   | Good                | No                  |
| 29 | 84   | Good                | No                  |
| 30 | 82.5 | Good                | No                  |
| 31 | 82   | Good                | No                  |
| 32 | 98   | Moderate            | Yes                 |

Good drainage condition is indicated with a presence of good channel, fluent water flow without any obstruction, and a relative good drainage construction (Fig. 1). Drainage with a hampered water flow due to waste and/or damaged construction is considered in the moderate category (Fig. 2). Fig. 3 describes the condition of puddles approaching the drainage canal which cannot flow smoothly due to
road distress and inappropriate slope of the road. An inappropriate slope could cause the absence of its function in channelling water to the edge and continuing to drainage channel (Fig. 4).

Table 2. PCI Score Category

| PCI Classification | PCI Score |
|--------------------|-----------|
| Good               | 100 – 85  |
| Satisfactory       | 85 – 70   |

3. Analysis and Discussion

Figure 5. (a) Distribution of distress level based on drainage conditions, (b) distribution of puddle conditions based on drainage conditions.

Fig. 5 (a) describes the lowest level of road distress caused by two drainage conditions, reaching 62% for good drainage and 73% for moderate drainage. Good and moderate drainage conditions cause low-level road distress. Figure 5 (b) describes the condition of the presence of puddles on pavement surfaces in both drainage conditions with a percentage of 53% in good drainage and 62% in moderate drainage.

3.1. Data Processing Using Factor Analysis

In this study, researchers used three factors, A (drainage channel conditions), B (surface water conditions), and C (PCI scores), with description as follows:

Drainage Channel Conditions (A); A1 = Good
A2 = Moderate

Surface Water Conditions (B); B1 = There is a puddle
B2 = There is no puddles

PCI Score (C); C1 = Good PCI Score (100-85)
C2 = Satisfactory PCI Score (84-70)

And the three variance analysis factor for the fixed effect (influence):

Ho : $\tau_i = 0$  \quad H1 : $\tau_i \neq 0$
Ho : $\beta_j = 0$  \quad No major influence  \quad H1 : $\beta_j \neq 0$
Ho : $\gamma_k = 0$  \quad H1 : $\gamma_k \neq 0$
Ho : $\tau_i \beta_j = 0$
Ho : $\tau_i \gamma_k = 0$
Ho : $\beta_j \gamma_k = 0$
Ho : $\tau_i \beta_j \gamma_k = 0$

$H_0 : \tau_i \beta_j \neq 0$
$H_0 : \tau_i \gamma_k = 0$
$H_0 : \beta_j \gamma_k = 0$
$H_0 : \tau_i \beta_j \gamma_k \neq 0$

Initial hypothesis (Ho) shows no main effect of (A, B, C) while interaction effect of (AB, AC, BC, and ABC) is real (significant).

3.2. Construction Design of Experiments

From the results of PCI score calculation (C), it is done a factorial analysis $2^3$ using surface water condition factor (B) and drainage condition factor (A) to determine the effect of these three factors on the road distress level. Experiments are carried out using 3 causal factors (A, B, and C) with r repetition ($r = 3$) and each experiment contains all treatment combinations of a, b, and c, thus it would be easier to arrange them in factorial designs.

There are 24 of 32 samples used in experimental design because from 32 samples, there is no even distribution of survey results that fills in each block of code. Therefore only replication 3 can be used with a sample size of 24. The following table is the construction of experimental design of the study.

Table 3. Construction of Experiments Design

| PCI Score | Puddles condition (B) | Drainage Channel Conditions (A) |
|-----------|-----------------------|---------------------------------|
|           | There is a puddle    | There is no puddles             |
|           | Good                  | Good                            |
|           |                       | Moderate                         |
| Good      | 87.6                  | 98                              |
|           | 95.6                  | 98                              |
|           | 92                    | 98                              |
| PCI (C)   | 83                    | 75                              |
| Satisfactory | 85                | 84                              |
|           |                       | 85                              |
|           |                       | 79                              |

3.3. Factorial Analysis $2^3$

Factorial design is used to examine two or more independent variables in an experimental situation.

Table 4. Yates Method for Determining Contrast

| Treatment | Responses | Column 1 | Column 2 | Column 3 |
|-----------|-----------|----------|----------|----------|
| I         | 275.2     | 522.2    | 1055.6   | 2079.1   | 180,110.7 |
| A         | 247       | 533.4    | 1023.5   | -151.3   | 953.82    |
| B         | 281.9     | 521.6    | -58.6    | -8.5     | 3.01      |
| Ab        | 251.5     | 501.9    | -92.7    | 6.7      | 1.87      |
| C         | 286.2     | -28.2    | 11.2     | -32.1    | 42.93     |
| Ac        | 235.4     | -30.4    | -19.7    | -34.1    | 48.45     |
| Bc        | 271.9     | -50.8    | -2.2     | -30.9    | 39.78     |
| Abc       | 230       | -41.9    | 8.9      | 11.1     | 5.13      |

Factorial design is used to examine two or more independent variables in experimental situations.
### Table 5. List of ANOVA experimental design results

| Sources of Variation | df  | Sum of Square | Mean of Square | F_count | P_value |
|----------------------|-----|---------------|----------------|---------|---------|
| Average Treatment    |     | 180,110.70    | 180,110.70     |         |         |
| A                    | 1   | 953.82        | 953.82         | 64.69   | 0.000   |
| B                    | 1   | 3.01          | 3.01           | 0.20    | 0.657   |
| AB                   | 1   | 1.87          | 1.87           | 0.13    | 0.726   |
| C                    | 1   | 42.93         | 42.93          | 2.91    | 0.103   |
| AC                   | 1   | 48.45         | 48.45          | 3.29    | 0.089   |
| BC                   | 1   | 39.78         | 39.78          | 2.70    | 0.12    |
| ABC                  | 1   | 5.13          | 5.13           | 0.35    | 0.563   |
| Error                | 16  | 235.91        | 14.74          |         |         |
| Total                | 24  | 181,441.61    |                |         |         |

Based on the analysis result, it can be concluded that:

- Drainage condition factor (A) with a P value that states F_count= 64.69 has opportunity of P=0.000 **not to reject** Ho : τ_i = 0
- Surface water condition factor (B) with a P value that states F_count= 0.20 has opportunity of P=0.657 to **reject** Ho : β_j = 0
- PCI score factor (C) with a value of P that states F_count= 2.91 has opportunity of P=0.103 **not to reject** Ho : γ_k = 0

The result shows that the most influential factor is A, followed by C and B while the most influential interactions are AC, followed by BC, ABC and AB.

#### 3.4. Fractional Effects Analysis

2^(4-1)

Calculation of the effect value is done by half-reaction analysis to give descriptions and changes of effect. Each fraction factorial contains a full factorial in fewer factors. The one-half fraction will project into complete factorial at each k-1 from original factor.

For the main fraction, contrast used to estimate the main effect of A is exactly the same as contrast used to estimate BC interaction. This phenomenon is called aliasing and it occurs in all fraction designs. Aliases can be found directly from columns in tables + and - signs.

The main effect aliases with three factor interactions, namely: A.I=A^2=B^2=CD, B.I=AB^2=CD, C.I=AB^2=CD, A.B=AB^2=CD, and D.I=ABC^2=AB, two factor interaction interacts with two factor interaction namely: AB.I=A^2B^2=CD, AC.I=BD, AD.I=BC. Thus there are only 7 effects that can be estimated: A, B, C, D, AB, AC, and AD. Using experiment result in **Table 6**, it is done half reaction analysis with 8 combinations.

### Table 6. ANOVA half fractions using experimental results

| Surface Water Conditions (B) |      |  |      |  |  |  |  |
|-------------------------------|------|------|------|------|------|------|------|
| There’s a Puddle              |      |  |      |  |  |  |  |
| Drainage Channel Conditions (A) |      |  |      |  |  |  |  |
| Good                          |      |  |      |  |  |  |  |
| PCI Score                     |      |  |      |  |  |  |  |
| Good                          |      |  |      |  |  |  |  |
| (-1)                          | 275.2| C = 286.2| B = 281.9| BC = 271.9|
| Satisfactory                  |      |  |      |  |  |  |  |
| A                             | 247  | AC = 235| AB = 252| ABC = 230|
Table 7 Observations of Experimental Results using $2^{4-1}$ design

| Treatment | Basic Design | D = ABC | Combination Treatment | Y   |
|-----------|--------------|---------|-----------------------|-----|
| 1         | - - - -     | 1       |                       | 275.2 |
| 2         | + - - +     | Ad      |                       | 247  |
| 3         | - + - +     | Bd      |                       | 281.9|
| 4         | + + - -     | Ab      |                       | 251.5|
| 5         | - - + +     | Cd      |                       | 286.2|
| 6         | + - + -     | Ac      |                       | 235.4|
| 7         | - + + -     | Bc      |                       | 271.9|
| 8         | + + + +     | Abcd    |                       | 230  |

Figure 6 Geometric main effects

The results are summarized in Table 8.

Table 8 Calculation of Effects Estimation for $2^{4-1}$ Design

| No. | Basic Design | ABC | Y     | Estimated Effect |
|-----|--------------|-----|-------|------------------|
|     | A  B  C     |     |       | A  B  C  D  AB  AC  BC |
| 1   | -1 -1 -1 -1 | 275.2 | -275.2 | -275.2 | -275.2 | -275.2 | 275.2 | 275.2 |
| 2   | 1 -1 -1 1   | 247  | 247   | -247   | -247   | -247   | -247   | -247   |
| 3   | -1 1 -1 1   | 281.9 | -281.9 | 281.9  | -281.9 | 281.9  | -281.9 | 281.9  |
| 4   | 1 1 -1 -1   | 252  | 251.5 | 251.5  | -251.5 | -251.5 | 251.5  | -251.5 |
| 5   | -1 -1 1 1   | 286.2 | -286.2 | -286.2 | 286.2  | 286.2  | -286.2 | 286.2  |
| 6   | 1 -1 1 -1   | 235  | 235.4 | 235.4  | -235.4 | -235.4 | 235.4  | -235.4 |
| 7   | -1 1 1 -1   | 271.9 | -271.9 | 271.9  | -271.9 | -271.9 | 271.9  | -271.9 |
| 8   | 1 1 1 1     | 230  | 230   | 230    | 230    | 230    | 230    | 230    |

|               | -37.825 | -2.125 | -8.025 | 2.775  | 1.675  | -8.525 | -7.725 |

Table 9 shows that the main effect factors A, C, and D is quite big.
Table 9 Estimation of the Securities and aliases

| Probe  | Alias structure | \( \ell_{A} = -37.825 \) | \( \ell_{A} \rightarrow \) A +BCD |
|--------|-----------------|---------------------------|----------------------------------|
| \( \ell_{B} = -2.125 \) | \( \ell_{B} \rightarrow \) B +ACD |
| \( \ell_{C} = -8.025 \) | \( \ell_{C} \rightarrow \) C +ABD |
| \( \ell_{D} = 2.775 \) | \( \ell_{D} \rightarrow \) D +ABC |
| \( \ell_{AB} = 1.675 \) | \( \ell_{AB} \rightarrow \) AB +CD |
| \( \ell_{AC} = -8.525 \) | \( \ell_{AC} \rightarrow \) AC +BD |
| \( \ell_{AD} = -7.725 \) | \( \ell_{BC} \rightarrow \) BC +BC |

If A, C and D are big enough, it could be concluded that 2 aliases interaction of AC+BD and AD+BC have big effect because of AC and AD are also significant. In other word, if A, C and D are significant, then significant interactions are AC and AD.

4. Conclusion

From the result presented above, it could be concluded that: The five surveyed areas are dominated by good drainage conditions, no puddles on the pavement and LOW distress level. There are 9 types of road distress in this study. Longitudinal Cracking dominates while slipping is the least. Based on PCI method, the five surveyed locations are dominated by “Good” PCI and “Routine Maintenance”. Based on ANOVA statistical test, the most influential factor on pavement distress is drainage condition with F-count of 64.69 while surface water gives a slightly influence with F-count of 0.2. Factorial analysis design of 2⁴⁻¹ obtains running Minitab of Regression Equation: \( Y = 259.9 - 18.91 C - 1.063 B - 4.013 A + 0.8375 AC - 4.262 BC - 3.863 AB + 1.388 ABC \) with A = PCI score, B = water surface condition, and C = drainage condition. The better the drainage condition, the less the pavement distress with the higher PCI score and vice versa.

It is suggested to do a further research on the factors of rainfall, slope, road class and more samples with severity distress level on pavement to represents higher population.

Acknowledgements

This study is supported by Grant PIT-9 2019 No. NKB-0076/UN2.R3.1/HKP.05.00/2019 funded by DRPM Universitas Indonesia. The author thanks the various parties who contributed to the success of the study and especially the Directorate of Research and Community Development, Universitas Indonesia.

References

[1] Iskandar D, Hadiwardoyo S P, Sumabrata R J and Fitriasari I N 2018 Road Maintenance Strategy with Characteristic of Drainage Condition based on Pavement Performance 040010
[2] Tawalare A and Raju K V 2016 Pavement Performance Index for Indian rural roads Perspect. Sci. 8 447–51
[3] Mia M N U, Henning T and Costello S 2015 Life cycle cost analysis to identify the need for drainage renewal in maintenance of road asset: Case Studies from a New Zealand road network 9th Int. Conf. Manag. Pavement Assets 5165
[4] Chen X, Dong Q, Zhu H and Huang B 2016 Development of distress condition index of asphalt pavements using LTPP data through structural equation modeling.pdf 58–69
[5] Islam S and Buttlar W G 2012 Effect of Pavement Roughness on User Costs 2285 47–55
[6] Shahin M Y 1994 Pavement Management for Airports, Roads and Parking Lots (Springer-Science+ Business Media, B. V.)
[7] Shah Y U, Jain S S, Tiwari D and Jain M K 2013 Development of Overall Pavement Condition Index for Urban Road Network Procedia - Soc. Behav. Sci. 104 332–41
[8] Kathleen T Hall C E C 2003 Effect of Subsurface Drainage on Performance of Asphalt and Concrete Pavements