The use of Local Aggregate for Eco-Drainage Component, Rigid Porous Pavement

by Isri Ronald Mangangka

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***Abstract*—Implementation of environmentally friendly drainage system (eco-drainage) is an effort to reduce the environmental quality degradation, including quality and quantity of runoff. With eco-drainage concepts, stormwater management is not only focused on runoff quantity, but more integrated in quantity and quality management with additional objectives of amenity, landscapes and aesthetics, water conservation and ecological restoration.**

The eco-drainage concept is implemented through three methods: detention system, retention system and infiltration system. The use of "porous pavement" in light-load road construction is one method of infiltration systems. Porous pavement as an alternative to conventional impermeable pavement has many advantages in terms of rainwater management. The porous pavement surface causes stormwater infiltrates and percolates into the base course and sub-base of the road and then to sub-grade. The advantages of porous pavement is to reduce peak discharge, improve groundwater refill and improve the quality of surface water (runoff).

To increase the carrying capacity of porous pavement construction, pore size and quantity must be reduced, on the other hand to increase infiltration capacity, the size and quantity of pore should be increased. This study aims to produce aggregate compositions on concrete mixtures for rigid porous pavement construction, which is strong enough with adequate infiltration capacity. The optimal aggregate composition was obtained through laboratory experiments based on several mixed concrete design compositions. Samples were made according to different aggregate compositions, then tested their strength (carrying capacity) and their infiltration capacity. The best aggregate composition is obtained by sample that has adequate strength to support vehicle load and also has sufficient infiltration capacity.

Rigid porous pavement construction design is expected to be applied to road construction with light load as an eco-drainage component. In order to have economic value, this research utilize local aggregate with previously prepared for different gradations. This study used two aggregate types based on the source of the collection, aggregates from Kinilow, Tomohon City (Kinilow Aggregates) and aggregates from Lansot, North Minahasa Regency (Lansot Aggregates).

In addition to obtaining an optimal combination of the strength of this rigid porous pavement construction and infiltration capacity, this study also aims to determine the relationship between this combination with the aggregate properties. This relationship is obtained through statistical analysis of multivariate analysis.

The results of statistical analysis indicate a relationship between the strength of the construction and the properties the aggregate. The results show the same trend of relationship between carrying capacity and infiltration rate for samples from both Kinilow Aggregates and Lansot Aggregates. However, the study results also show the differences of the construction strength and the infiltration capacity and their correlation to the properties of the aggregates. The results also show that both local aggregates are very suitable to be used for construction material of porous concrete pavement. Samples with minimum aggregate size of 2.36 mm still have more than enough infiltration capacity to infiltrate runoff from high intensity rainfall with 5 minutes duration for 10 years and 20 years return period design rainfall. Furthermore, Samples with minimum aggregate size of 9.525 mm, which have very big infiltration capacity, still have adequate carrying capacity to be used for street pavement.

Keywords - rigid porous pavement; porous pavement; eco-drainage

I. INTRODUCTION

The implementation of eco-drainage system in urban stormwater management is one effort to answer the problem of environmenal degradation. Traditional urban stormwater management principles are primarily built on flood mitigation. In the past, little attention and resources have been allocated for mitigating the environmental impacts of urbanisation. Due to this, most traditional urban drainage systems have been developed with a high degree of conveyance capacity to minimise the risk of flooding. However, the growing public awareness of environmental issues in recent years has led to stormwater management with dual focus [1]. This is achieved by providing integrated management of water quantity and water quality with a range of supplementary objectives relating to amenity, landscape and aesthetics, water conservation and ecological restoration [2] [3] [4].

Further about eco-drainage system, where in Australia is known as Water Sensitive Urban Desain (WSUD), while in the USA is known as Sustainable Urban Drainage System

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(SUDS), there is a stormwater management concept which not only focuses on the drainage system but a comprehensive stormwater management that also concern to the environmental quality. Some detailed research have been conducted regarding the performance of WSUD/SUDS compnents as the structural component of eco-drainage system in reducing the quantity and quality of stormwater, such as study of the constructed wetland treatment performance [5] and study of the bioretention basin treatment performance [6].

Porous Pavement is one of some well known eco-drainage components. It is an integrated eco-drainage component which is not only usefull in treating the quantity and quality of stormwater but also amenity, landscape and aesthetics, water conservation and ecological restoration. Porous pavement is permeable street pavement which promotes stormwater to infiltrate and percolate into the soil.

Porous pavement as an eco-drainage component has been exploited and built in large quantities in developed countries such as the United States and Australia. They have production guidelines based on the results of their studies according to the conditions in their country. Although porous pavement has been successfully developed in many cities in the world, but the availability of local aggregate as raw materials as well as conditions of rainfall properties that are very different from the conditions in Indonesia, this causes that their production guidelines must be reviewed before being implemented in Indonesia.

II. Literature Review

A. *Porous Pavement*

Environmentally friendly drainage (eco-dranage) concept can be classified into three systems: detention system, retention system, and infiltration system. Porous pavement is one of infiltration system. Porous pavement is a permeable road layer covering the road construction because the layer has pores so that the water retained above the cover layer will be infiltrated through the pores. Porous pavement is a pavement made with limited fine aggregate proportion. Porous pavement contains relatively large pores that is evenly spreaded in the layer. These pores allow water to flow from the road surface into the ground below.

Porous pavement can remove sediment, nutrients, heavy metals and hydrocarbons from contaminated runoffs through a process called adsorption. Adsorption is the process of absorption of a substance to the surface of the material/ substance. In this process, the absorbed substance attaches to the absorbent surfaces. Studies have shown that porous pavement is very effective in retaining dissolved metals [7].

Porous pavement can be either flexible pavement or rigid pavement [8]. Flexibel pavement is a pavement construction made using asphalt material as a binder, while rigid pavement uses cement (concrete) material. Thus, porous pavement using asphalt is called flexible porous pavement while using concrete material is called rigid porous pavement.

In rigid pavement construction, the main structure of the pavement is a layer of concrete plate, hence the pavement is also called concrete pavement. Rigid pavement is conducted for soil with low carrying capacity or big traffic load.

Saodang [9] divides rigid pavement (concrete pavement) into 5 types:

1. Jointed concrete pavement without reinforcement
2. Jointed reinforced concrete pavement
3. Continuosly reinforced concrete pavement
4. Prestressed concrete pavement
5. Fiber reinforced concrete pavement

B. *Hydrological Analysis*

The hydrological analysis in this study is intended to obtain the maximum intensity of rainfall that can occur in Manado, then it is test whether the rigid porous pavement design has enough infiltration and percolation capacity for this rain intensity. The analysis starts from determining the amount of rainfall design, followed by calculation of rain intensity for each duration of rain. The intensity of the precipitation to be analyzed is the intensity for the 10-year and 20-year return periods, since the rigid porous pavement is equivalent to the minor drainage system.

Oulier Detection

Before rainfall data is analyzed to get rainfall design, outlier data test is firstly conducted. It is to know whether there is extreme rainfall data due to negligence in recording or extreme condition is happened. Outlier data test is performed for high outlier and low outlier, based on skewness coefficient (CsLog):

- If $Cs_{Log} > 0.4$, high outlier test is conducted first
- If $Cs_{Log} < -0.4$, low outlier test is conducted first
- If $-0.4 < Cs_{Log} < 0.4$, high outlier test and low outlier test is conducted together.

with

$$CS_{Log} = \frac{n\sum_{i=1}^{n}\left(Log\,X_i - \overline{Log\,X}\right)^3}{(n-1)(n-2){S_{Log}}^3}$$

where:

X_i = Maximum daily rainfall in year i
$\overline{Log\,X}$ = Average of observed rainfall logaritmic value
CS_{Log} = Logaritmic skewness coeficient
S_{Log} = Logaritmic standard deviation
n = The number of data

Threshold for high outlier (X_H) is obtained from $Log\,X_H = \overline{Log\,X} + (S_{Log} \times K_n)$, while for low outlier (X_L) is obtained from $Log\,X_L = \overline{Log\,X} - (S_{Log} \times K_n)$.

where:

$$S_{Log} = \sqrt{\frac{\sum_{i=1}^{n}\left(Log\,X_i - \overline{Log\,X}\right)^2}{n-1}}$$

Design Rainfall Analysis

The purpose of the rainfall frequency analysis is to obtain the design rainfall for some return periods according to some distribution types. In this research, analysis is conducted to three distribution type, i.e. Gumbel Type I distribution, Two Parameters Log-normal distribution and Log Pearson Type III distribution.

The empirical formula for Gumbel Type I distribution is:

$$X_t = \bar{X} + (S \times K_G)$$

where:

- X_t = Design rainfall for return period of t years (mm)
- $\bar{X}$ = Data mean (mm)
- K_G = Frequency factor, calculated with $K_G = \frac{Y_T - Y_n}{S_n}$
- Y_T = Reduced variate expected to occur for T year return period, calculated with $Y_T = -L_n \left\{-L_n \left[\frac{T(x)-1}{T(x)}\right]\right\}$
- Y_n = Reduced mean
- S_n = Reduced standard deviation
- S = Std. deviation, calculated with $S = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X)^2}{n-1}}$

The transformation formula for Two Parameters Log-normal distribution is:

$$Log\ X_t = \overline{LogX} + (K.SLog\ X)$$

where:

- K = Frequency factor as a function of variation coefficient (Cv) for t years return period.
- Cs = Skewness coefficient = $3Cv + CV_3$
- C_K = Curtosis coefficient = $Cv_8 + 6Cv_6 + 15Cv_4 + 16Cv_2 + 3$
- Cv = Variation coefficient = $\frac{\sigma}{\mu}$
- σ = Population standard deviation of Ln X or log X
- μ = Population mean of Ln X or log X

Log-Pearson Type III distribution is the transformation from Pearson Type III distribution by changing the data to be logaritmic data. The formula of Log-Pearson Type III distribution is as follow:

$$Log\ X_t = \overline{LogX} + (G \times S)$$

where:

C_S = Skewness coefficient

$$= \frac{n.\sum\left(logX - \overline{logX}\right)^3}{(n-1)(n-2)\left(\overline{SlogX}\right)^3}$$

C_K = Curtosis coefficient

$$= \frac{n^2.\sum\left(logX - \overline{logX}\right)^4}{(n-1)(n-2)(n-3)\left(\overline{SlogX}\right)^4}$$

Rainfall Intensity

Rainfall intensity is the rain depth or the volume of rainfall per time unit. The rainfall intensityanalysis is conducted by using Mononobe formula. The intensity of rainfall is highly dependent on time of concentration (tc) of the surface runoff flow in the catchment area. The time of concentration of the rainfall is the time required for the flow of water from the farthest point to a particular point observed in the catchment area. The Mononobe formula to calculate rainfall intensity is as follows:

$$I = \frac{R_{24}}{24} \cdot \left(\frac{24}{tc}\right)^{2/3}$$

where:

- I = Rainfall Intensity (mm/hour)
- R_{24} = Daily rainfall depth (mm)
- tc = Time of Concentration (hour)

III. Results and Discussioin

A. Hydrological Analysis Result

The hydrological analysis in this study used rainfall data collected from *Badan Meteorologi, Klimatologi dan Geofisika (BMKG)* Manado for Kayuwatu climatology station during the last 10 years of observation (2007 to 2016) (see Table 1).

TABLE I. 10 Years Annual Maximum Daily Rainfall

No.	Year	Rainfall Depth (mm)
1	2005	38,30
2	2006	74,00
3	2007	108,00
4	2008	70,00
5	2009	50,30
6	2010	76,10
7	2011	57,00
8	2012	90,20
9	2013	80,60
10	2014	170,00

The data first become subject to test their outlier. Because $CS_{Log} > 0.4$, high outlier test was firstly conducted, then low outlier test. However, the result show that there is no outlier detected.

Design rainfall analysis has been conducted to three distribution type, i.e. Gumbel Type I distribution, Two Parameters Log-normal distribution and Log Pearson Type III distribution. The result of design rainfall analysis to the three distribution type is summerised in the following table.

TABLE II. Result of Design Rainfall Analysis

No.	Return Period (Year)	Design Rainfall (mm)			
		Gumbel Tipe I Distribution	2 Parameter Log-Normal Distribution	Log-Pearson Tipe III Distribution	Maximum
1	2	76,447	73,736	73,107	76,447
2	5	120,515	105,621	107,506	120,515
3	10	149,692	128,956	130,203	149,692
4	20	177,680	153,019	157,929	177,680
5	25	186,558	158,207	164,145	186,558
6	50	213,907	186,911	191,956	213,907
7	100	241,054	214,607	221,992	241,054

Design daily rainfall chosen depends on the return period, while the return period selection is based and depends on the level of risk and construction cost. Shorter return period reduces the construction cost, consequently risk of loss and damage will be greater. Conversely, longer return periods increases the construction cost but less risk of losses and demage.

In this study where the location of the intended structure is a parking lot that could be located in a dense business area, the return periods chosen are 10 and 20 years. Accordingly, from Table II, the design daily rainfall for the 10-year return period is 149.69 mm and for the 20-year return period is 177.68 mm. Thus, using the above mononobe formula, the relationship between rainfall intensity and rainfall duration for rainfall with

10-year or 20-year return period is presented by Intensity-Frequency-Duration (IFD) Curve in Figure 1 below.

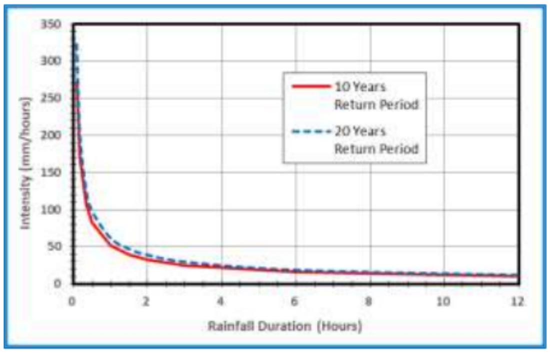

Fig. 1. Intensity-Frequency-Duration (IFD) Curve

The scope of this research is drive way and parking lot, where the catchnya area is relatively small. For a small catchment area, the maximum rainfall intensity is usually selected based on short duration rainfall, in this case 5 minutes duration. The result calculation using Mononobe formula shown that for 5 minute duration rainfall, the intensity for the design rainfall with a 10-year return period is 272 mm/hour, while the intensity for the design rainfall with 20-year return period is 323 mm/hour.

Performance of the porous pavement can decrease over time. This is due to clogging of pores with soil material carried by runoff [10] [11] [12]. Therefore, porous pavement design should take into account the effect of this clogging. Lucke [13], after studying the infiltration capacity of 8 years old permeable pavement said that porous pavement infiltration rate decreases over time and the reduction of the infiltration capacity is 63.3% to 100%.

To compensate the possibility of future clogging, the design rain intensity to be received by the porous pavement construction in this study is assumed to be 2 times, or to be 646 mm/hour for rain with 20-year return period and 544 mm /hour for rain with 10-year return period. This value will be used as the threshold of percolation/permeability rate needed for Manado region.

B. Concrete Mix Design

Both types of material, which comes from Lansot and Kinilow, were made thir concrete mixture samples. For both types of aggregates, samples were prepared with different aggregate compositions, in this case the different aggregate compositions are categorized as Coarse, Medium and Fine. The minimum grain size for Coarse is 3/8 ", for Medium is 4.75 mm (No. 4), and for Fine category is 2.36 mm (No. 8).

The number of samples for Kinilow materials is 9 samples, consist of 3 samples for each category (coarse, medium and fine), while the number of samples for Lansot material is 6 samples, consist of 2 samples for each category.

C. Permeability and Concrete Strength Test Results

After 7 days, samples were tested their infiltration rate and compressive strength. The 7 days concrete compressive strength is then converted to 28 days compressive strength according to regulation given in Peraturan Beton Indonesia (PBI). The infiltration testing procedure is carried out according to the Standard Nasional Indonesia (SNI), which is modified to be performed on 15 cm x 15 cm x 15 cm concrete cube. In the infiltration test, the water infiltration rate is measured when the sample is very saturated, giving constant infiltration rate, thus the infiltration rate obtained is actually the percolation rate, or the permeability coefficient. Test results are given in Table III.

TABLE III. INFILTRATION AND COMPRESSIVE STRENGTH RESULTS

Aggregate From	Classificaiton	Sampel Code	Infiltration Rate L/sec	Permeability (in 000) mm/jam	7 Days Compressive Strength (kg/cm²)	28 Days Compressive Strength (kg/cm²)
KINILOW	FINE	KF1	0.065	10.40	153.41	236.02
		KF2	0.067	10.72	155.05	238.54
		KF3	0.063	10.08	152.19	234.14
	MEDIUM	KM1	0.178	28.48	112	172.31
		KM2	0.181	28.96	107	164.62
		KM3	0.161	25.76	117	180.00
	COARSE	KC1	0.327	52.32	83.28	128.12
		KC2	0.316	50.56	88.79	136.60
		KC3	0.342	54.72	86.14	132.52
LANSOT	FINE	LF1	0.028	4.48	187.77	288.88
		LF2	0.031	4.96	187.05	287.77
	MEDIUM	LM1	0.155	24.80	139.65	214.85
		LM2	0.161	25.76	134.56	207.02
	COARSE	LC1	0.310	49.60	118.35	182.08
		LC2	0.285	45.60	117.53	180.82

Interpretation of The Infiltration and Compressive Strength Test Results

Test results given in Table III are also presented in Fig.2 below. The graph in Fig. 2 shows the relationship between permeability and compressive strength.

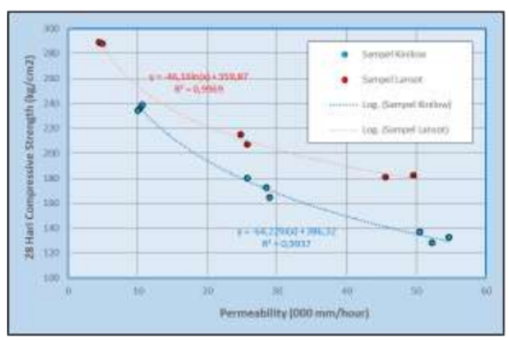

Fig. 2. Permeability versus 28 Days Compressive Strength

The graph shows that samples shall be separated according to their material source and each local material, Kinilow aggregates or Lansot aggregates, form its own curve. As shown in Fig. 2, the Kinilow samples (form blue line) have their own trends that are different from the trend of Lansot samples (form red line), therefore the results of this test can not be combined to produce only one graph. It can be concluded that different material location produces its own material properties and conditions, compared to the material taken from somewhere else. Therefore, in designing the concrete mixture for the rigid porous pavement, it must be separated based on the source location of the material, because the nature of the the material properties for each location is unique.

The graph also shows that in general, samples using materials from Lansot are more strength than samples using materials from Kinilow. Therefore, the abrasion test results show that Lansot aggregate is stronger than Kinilow aggregate. Both graphs (Lansot graph and Kinilow graph) show that in the relationship between permeability and compressive strength; the greater the permeability, the lower the compressive strength, and the relationship is in exponential trend.

Table III and Fig. 2 present that all samples have compressive strength above 130 kg / cm2, which means that in terms of strength they all are qualified for rigid porous pavement construction, which is designed for low-load traffic that only requires concrete with a compressive strength of 100 kg / cm2. Table III and Fig. 2 also show that all samples meet permeability requirements because they have a permeability coefficient above the threshold of 646 mm/hour.

Relationship between Permeability and Minimum Aggregate Size

Logically it can be understood that the smaller the minimum aggregate size, the lower the permeability, contrary the larger the minimum aggregate size the greater the permeability. This is due to the pore size in which water will pass through, the larger the minimum aggregate size, the bigger the pore that promotes water to pass through. The relationship between the minimum aggregate size and the permeability is given in Fig. 3 below.

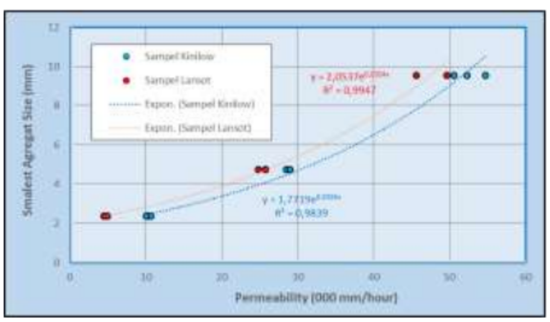

Fig. 3. Permeability versus Minimum Aggregate Size

It can be seen in Fig. 3 that the relationship between permeability and minimum agregat size is unique for each aggregate location. This support the hypotesis that each local material taken from different location must be tested separately before being used for rigid porous pavement construction. Fig 3 also shows that permeability and minimum agregat size for both types of aggregate form strong eksponensial trend relationship with coeffisien of determination of 0,995 and 0,984 (more than 95 % confidence level). This means that the trend can be used for further analysis.

Based on the researth results that all samples have permeability coefficient far above the thershold, by means that it is still posible to create the porous pavement concrete mixture with smaller minimum aggregate size which resulting samples with stronger compressive strength. Stronger compressive strength of porous pavement concrete may have wider range of application. Approximation of the minimum aggregate size that can be produced for these two type of aggregate can be analysed using the formula of relatiionship trend beetween permeability and aggregate minimum size (see Fig. 3).

Using the trend presented in Fig. 3, analysis results show that for rigid porous pavement construction, instead of 2.36 mm (No. 8), minimum size of agregat taken from Lansot might be 2.10 mm, while minimum size of aggregate taken from Kinilow mihbght be 1.81 mm. However, the availability of shieve size is limited. For Lansot, the smallest shieve size above 2.10 mm is 2.36 mm (No. 8), and for Kinilow, the smallest shieve size above 1.81mm is 2.00 mm (No. 10). Thus, the minimum aggregate size for Lansot material is 2.36 mm while for Kinilow material is 2.00 mm.

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