Effect of More Uniform Gradation on Permeability and Strength of Base Course for Porous Pavement

Ludfi DJAKFAR[a] , Yulvi ZAIKA[b], Hendi BOWOPUTRO[c]

[a,b,c] *Department of Civil Engineering, Universitas Brawijaya, Indonesia*
[a] *ldjakfar@ub.ac.id*
[b] *cicizaika@ub.ac.id*
[c] *bowoputro94@ub.ac.id*

Abstract: With the dwindling of open space in urban areas, any innovative work to conserve and protect the environment should be pursued. One such work is how to reduce water runoff during rainy season and conserve it by infiltrating it into the ground. This includes any roadway works by using the porous pavement. The objective of the study is to evaluate permeability capability and strength of base course when its gradation is moved toward more uniform. As many as 10 gradation schemes with 3 samples each were prepared and tested on CBR and permeability. The results showed that moving slightly the gradation toward more uniform increased its permeability capability significantly. In terms of its strength, the results showed a decrease up to 50 percent of its CBR value. It is recommended that this gradation type be used for light traffic road or parking lot.

Keywords: Porous Pavement, Permeability, CBR, Base Course

1. INTRODUCTION

The development of urban areas in Indonesia in recent years has shown a significant increase. It is estimated that by 2050 the number of people living in urban may reach 160 million (Tamin, 2004). This rapid increase has led to changes in land use. Many farmlands and open areas have been converted to residential and business areas.

The real consequence of this condition is a reduction of open land and its ability to infiltrate water into the ground, particularly during rainy season. Figure 1 may clarify this concept. In the suburban area, as many as 30% of rainwater may infiltrate to the underground, while in the inner city of urban area it may infiltrate up to only 5%. As a result, during the rainy season flooding almost occurs in almost all parts of the city. In addition, the water reservoir underground will also deplete, which may lead to the reduced underground water. This has become a common phenomenon in some large and medium cities in Indonesia. Flooding becomes a part of people's lives.

Considering this phenomenon, it is necessary for the government to have a clear policy in dealing with the problem, in all aspects, including in infrastructure development. Anything constructed should be environmentally friendly. In case of City of Malang, Indonesia, in some areas they have constructed a biopori or infiltration wells system to catch rainwater and infiltrate it to the ground.

For the sake of water conservation, this concept may also be applied in the construction of roads since it occupies more than 15% of the land. Furthermore, the philosophy of basic road design is not to allow water from entering the structure underneath, i.e., water should be removed as soon as possible from the road structure.

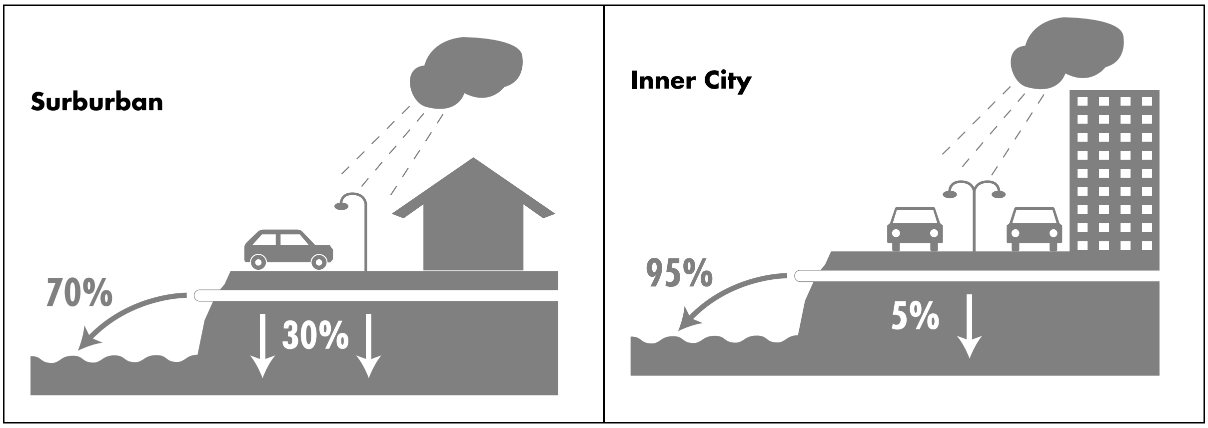

Figure 1. The effect of built area on water penetration (Interpave, 2009)

In order for the road construction to contribute to the the water conservation program, it is necessary to modify the design, i.e, it should allow water to enter the road structure without damaging it. One may use the porous pavement.

Porous pavement allows to penetrate the structure (Ferguson, 2005). The use of porous pavement has actually been practiced since the 1960s in Europe for the construction of airport runway (Zang et al, 2012). Currently about 90% of the construction of new road network in the Netherlands have adopted porous pavement (Huurman et al, 2009). The road rehabilitation policy in Japan is directed toward the use of porous pavement (Nakahara et al, 2004).

Studies by Hunt, et al (2006), found that the use of porous pavement reduces peak flow rate of runoff (peak flow rate) from 52% to 81%. In addition, the use of porous pavement has also reduced the volume of tracks that vary from 38% to 78%. Thelen (1978) recommends that for the porous pavement to perform, the base gradation should have an air void up to 40%. UNHSC (2009) recommends the aggregate gradation should meet the requirements as shown in Table 1.

As can be seen from Table 1, the gradation of porous pavement tend to go to more uniform. As such, there will be a reduction in its strength due to many gaps between the aggregate. In order for the aggregate to perform well in base course, its relation between strength and permeability capability should be investigated.

2. OBJECTIVE OF STUDY

The purpose of this study is as follows:

a. To determine the effect of permeability on the CBR value
b. To determine gradation band that will provide maximum permeability at permissible CBR value

3. METHODS

To achieve the research objectives, as many as 10 gradation variations with three (3) samples each were prepared, as shown in Figure 2 and Table 2. Note from Figure 2 that the control gradation was Var 5 since it was designed to lie inside the gradation band as specified by the Indonesian Highway Agency (Bina Marga), which was represented by BM UL and BM LL.

Table 1. Aggregate gradation for porous pavement (UNHSC, 2009)

US Standard Sieve Size Inches (mm)	Percent Passing (%)			
	Choker Course (AASHTO No. 57)	Filter Course (Modified NHDOT 304.1)	Réservoir Course (AASHTO No. 3)	Réservoir Course Alternative* (AASHTO No. 5)
6 (150)	-	100	-	
2½ (63)	-		100	-
2 (50)	-		90 – 100	-
1½ (37.5)	100		35 – 70	100
1 (25)	95 - 100		0 – 15	90 – 100
¾ (19)	-		-	20 - 55
½ (12.5)	25 - 60		0-5	0 - 10
3/8 (9.5)	-		-	0-5
#4 (4.75)	0 - 10	70-100	-	
#8 (2.36)	0-5		-	
#200 (0.075)		0 – 6**		
% Compaction ASTM D698 / AASHTO T99	95	95	95	95

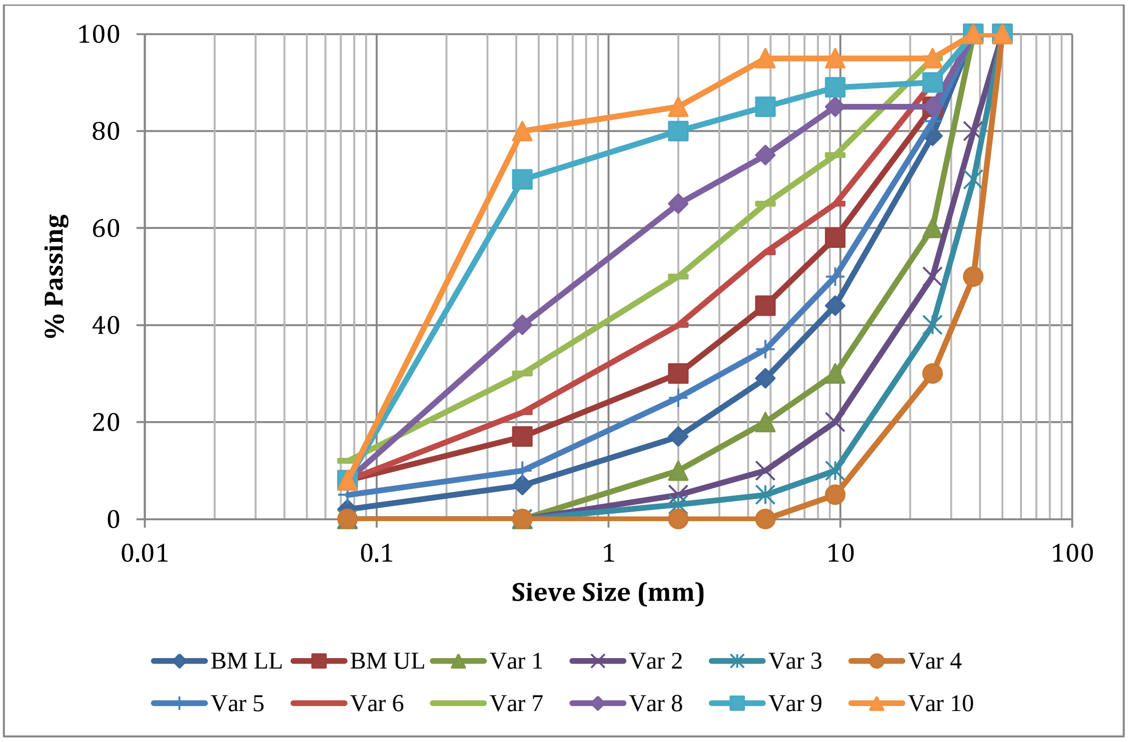

Figure 2. Design of experiments of gradation variation

For each gradation variation, a CBR and permeability test was performed to determine its CBR values dan permeability coefficient at each gradation level. The CBR test was performed using ASTM D 1883, while the permeability testing was performed using a Constant Head Test as specified by ASTM D 2434.

Table 2. Design of experiments of gradation variation

Sieve Size	Indonesian Specs		Gradation Variations									
	Lower Limit	Upper Limit	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
50	100	100	100	100	100	100	100	100	100	100	100	100
37.5	100	100	100	80	70	50	100	100	100	100	100	100
25	79	85	60	50	40	30	82	90	95	85	90	95
9.5	44	58	30	20	10	5	50	65	75	85	89	95
4.75	29	44	20	10	5	0	35	55	65	75	85	95
2	17	30	10	5	3	0	25	40	50	65	80	85
0.425	7	17	0	0	0	0	10	22	30	40	70	80
0.075	2	8	0	0	0	0	5	8	12	8	8	8

To determine the porosity for each sample, the following formula was used:

$$Porosity\varnothing = \frac{Pore\,Volume}{Total\,Mold\,Volume} \times 100\% \quad (1)$$

To determine the permebility coefficient (k), the following formula was used:

$$k = \frac{V \bullet L}{A \bullet t \bullet h} \quad (2)$$

where,

k : permebility coefficient
V : volume of water collected (cm^3)
L : height specimen (cm)
A : cross-section area of the test specimen (cm^2)
t : a graduated cylinder Charging time (sec)
h : height fall / head (cm)

To determine the CBR value the following formula was used:

$$CBR = \frac{unit\,test\,load\ (psi)}{standard\,unit\,load\ (psi)} \times 100\% \quad (3)$$

4. RESULTS

Table 3 and Figures 3 through 5 present the results of the laboratory tests for porosity, permeability and CBR testing.

Table 3. Results of porosity test

Gradation	Samples	Retained Water	Incoming Water	Porosity	Average Porosity
		mL	mL	%	%
X1	1	690	495.699	21.01623488	20.451
	2	680	505.699	21.44020642	
	3	740	445.699	18.89637715	
X2	1	610	575.699	24.40800723	24.408
	2	610	575.699	24.40800723	
	3	640	545.699	23.1360926	
X3	1	540	645.699	27.37580804	27.800
	2	510	675.699	28.64772268	
	3	540	645.699	27.37580804	
X4	1	490	695.699	29.49566577	28.930
	2	510	675.699	28.64772268	
	3	510	675.699	28.64772268	
X5	1	700	485.699	20.59226333	18.896
	2	740	445.699	18.89637715	
	3	780	405.699	17.20049097	

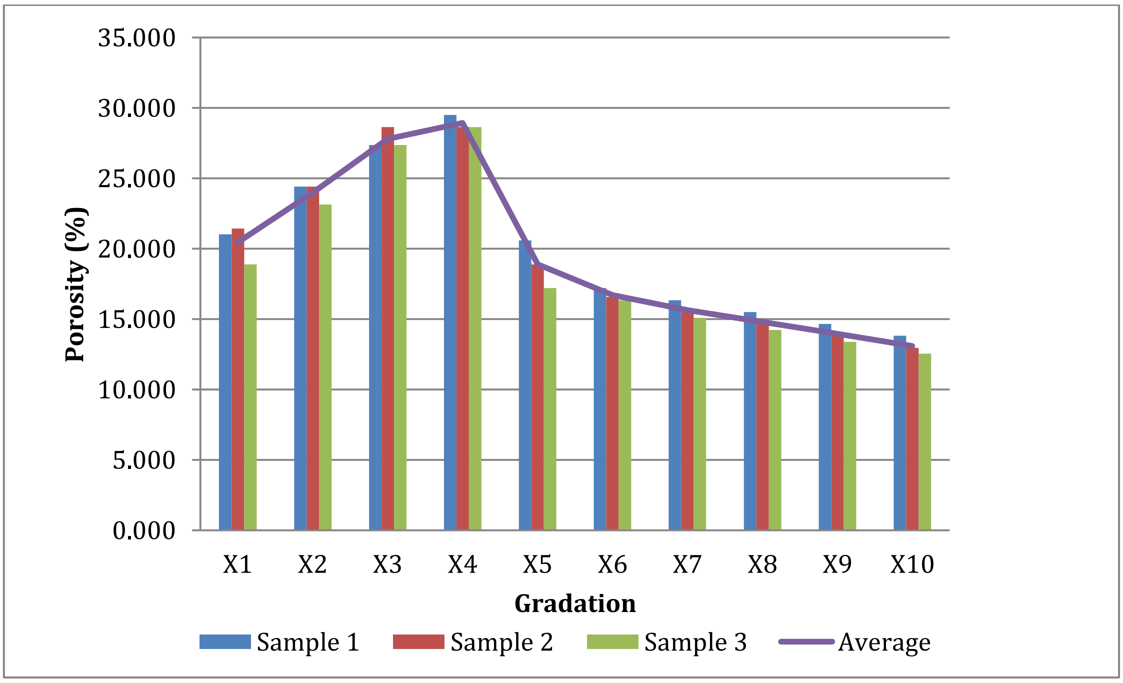

Figure 3. Porosity value for each gradation scheme

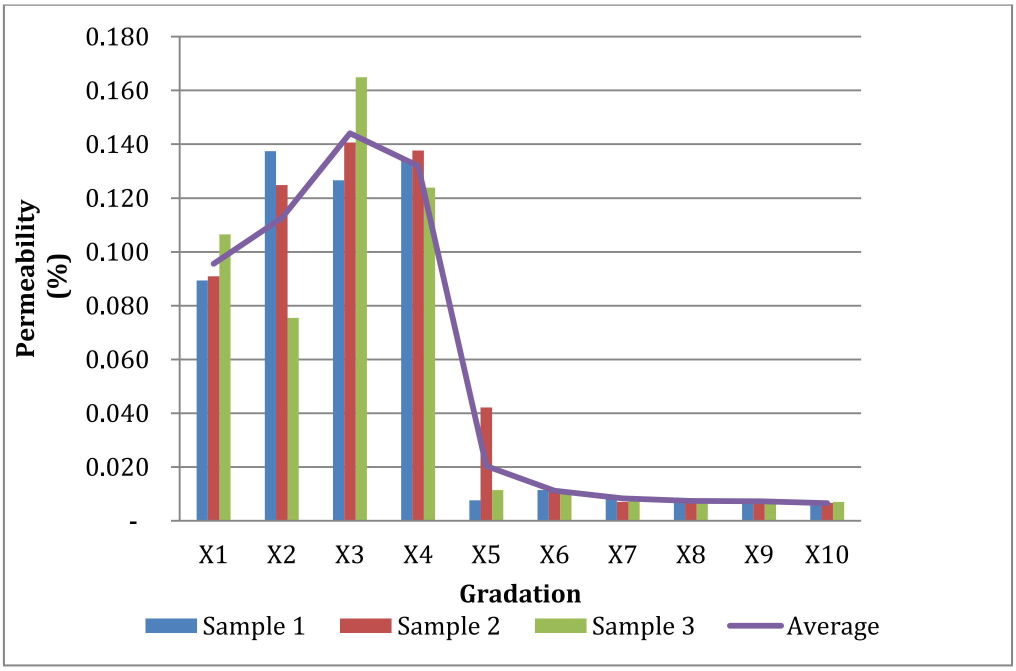

Figure 4. Permeabily coefficient (k) for each gradation scheme

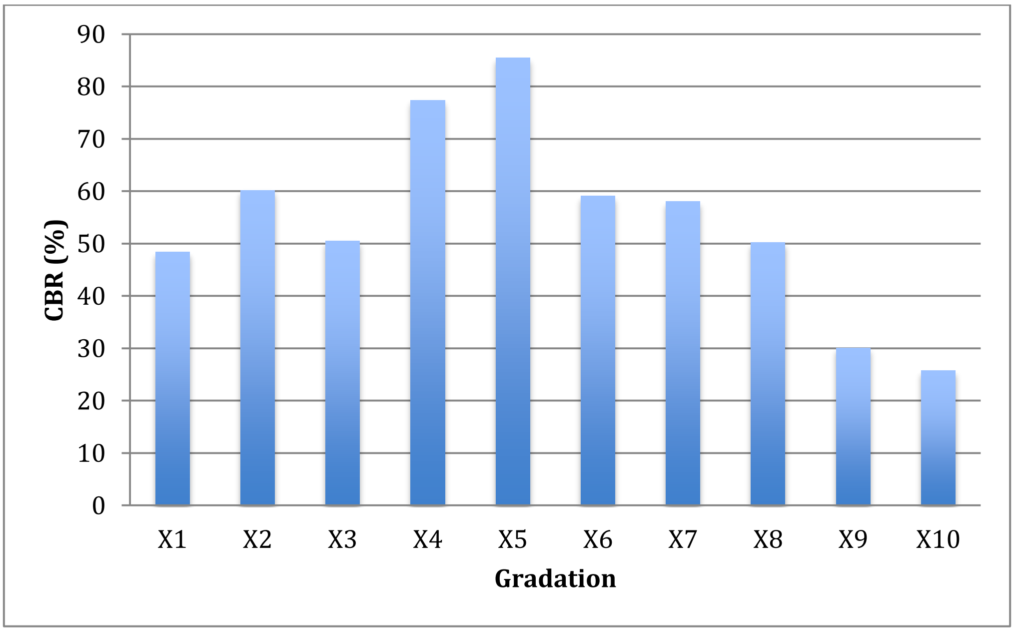

Figure 5. CBR value for each gradation scheme

As can be seen from Figure 4, there was a significant difference on the k value for courser material (X1 through X4) and finer materials (X6 through X10). In addition, changing gradation from the Indonesian Highway Standard (X5) to courser one such as X4 gradation increased the permeability capability by more than 500%.

As for the CBR value, changing the gradation scheme from the standard one (X5) to X4 has decreased the CBR about 10%, while changing to X3 gradation scheme decreased about 40%.

Figure 4 also shows that the best gradation scheme for permeability capability is X4 and X3, while in terms of CBR gradation scheme X4 results the best, followed by X2 and X3 as shown in Figure 5.

4.1. Selecting the Recommended Gradation Scheme

Figures 3 through 5 show that out of 10 gradations schemes, X3 and X4 seem to provide the best alternative for porous pavement foundation. Table 4 below summarizes this finding. As can be seen from the table, gradation scheme 3 provides the best alternative for permeability requirement, however, the CBR value drops by more than 40 percent out of the specified value. In such a case, base course with X3 gradation scheme may be suitable for area where medium traffic dominant while for lighter traffic and parking area, base course with X4 gradation can be the best choice.

Table 4. Change in CBR and permeability values due to gradation change

Gradation	CBR	Permeability (k)	Change in CBR (%)	Change in Permeability (%)
X5*	85	0.02	0	0
X4	77	0.132	-9.4	+560
X3	50	0.144	-41	+620

*Control variable

Figure 6 presents the comparison between gradation recommended by NAPA (1976) and result of this study. As can be seen from the figure, NAPA's gradation has more uniform gadation compared to this study, meaning that NAPA's will have better permeability but reduced strength.

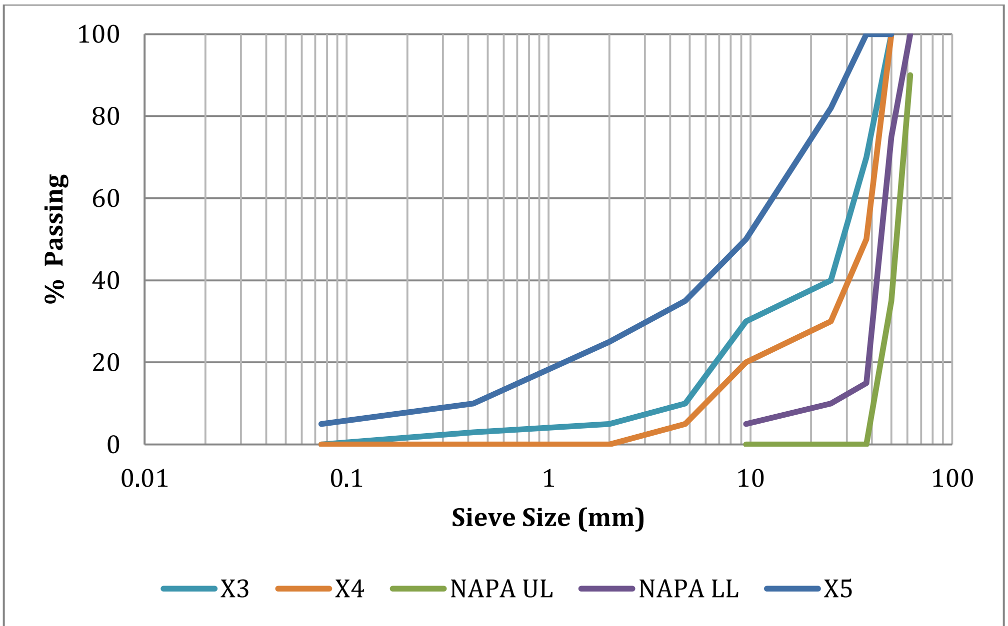

Figure 6. Comparison between NAPA's gradation (1978) and result of this study

It is plausible since porous pavement in the US is mostly used for parking lot, not for road or highway. The proposed gradation resulted from this study can be used for roadway with medium and light traffic.

Based on the result above the recommended gradation band for Indonesian condition is presented in Table 5.

Table 5. Recommended gradation band for porous pavement base course

Sieve Size (mm)	Upper Limit	Lower Limit
50	100	100
37.5	70	50
25	40	30
19	30	20
9.5	10	5
4.75	5	0
2	3	0
0.425	0	0
0.075	0	0

5. CONCLUSION AND RECOMMENDATION

The following conclusion can be drawn from the study:

1. Switching the gradation band into more uniform gradation produces a significant increase of permeability
2. The strength of the base, represented by its CBR value, may decrease up to 50% when the gradation is moved toward uniform one.
3. Due to its CBR decrease, it is recommended that porous pavement be used for light traffic or parking lot
4. Future research is still needed particularly to evaluate how this concept be implemented in the field and its performance be measured.

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