

GRADATION BAND OF SOME TYPES MATERIAL FOR RESERVOIR BASE OF POROUS PAVEMENT

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ABSTRACT: Recent year, reducing of open area and the extreme rainfall are reason for the flood in some city in Indonesia. The drainage and infiltrated well were constructed in some parts of the city could not solve the problem yet. The porous pavement can be applied to reduce run off, rate and pollutants. Reservoir base or sub base is an important layer as part of structure and also temporary store rainfall water before infiltrate to the subgrade. This study assessed characteristic and gradation some types of materials as stone crush, limestone and steel slag for porous pavement and evaluate this performance based on California Bearing Ratio (CBR) and porosity. Naturally these characteristics are contrary, in which for high porosity materials will have low bearing capacity. There are 7 gradations consist of 4 gradations in coarse aggregate and 3 gradations based on Bina Marga (Indonesian Highway Agency). The result showed that CBR of stone crush is high in uniform course material gradation than limestone and steel slag. In the term of porosity, the result completely the same for all materials in which the uniform gradation give the high porosity. It makes sign the influence of hardness and gradation of material will give contribution for bearing capacity and only gradation influence to porosity. The material are suitable for reservoir layer of porous pavement for light traffic load. Gradation band is lied between Bina Marga and NAPA and AASHTO specification.

Keywords: Porous, Pavement, Gradation, Reservoir, Material

1. INTRODUCTION

Development in urban area will change the land use. The farmland and open area will be converted to the residential and commercial area. It will reduce the infiltration rainfall water to the ground.

Climate change in various parts of the world such as rainfall is high enough to give direct effect to the pavement structure. In the beginning, road drainage system able to drain runoff to the sewer, but the increased rainfall causing puddles on the road surface. The surface flow becomes greater than the infiltration which is causes a negative effect on the structure, especially the structure of the pavement. This condition also occurred in Indonesia, where high rainfall became one of the causes of damage to the pavement structure.

One of the solutions offered in the pavement technology is the use of porous pavement that anticipate puddles of water on the road surface, in addition to increasing soil water infiltration. The pavement layer consists of base and surface layer that is able to flow the rainfall. For this purposes, material of the porous pavement must have two important properties which are able to support the weight of the vehicle and also porous. To find these characteristics in the material, CBR (California Bearing Ratio) test will conducted to determine resistance to load and porosity test to determine its ability to drain water.

California Bearing Ratio is the characteristic soil usually used as load capacity for highway construction. CBR is determined based on the rock type and gradation. There are several types of soil that has a high CBR due to rock hardness origin, but it must be supported with proper gradation such as stone crush, limestone.

In general, the use of crushed stone pavement on the foundation layer because it has a large bearing capacity. In this study used two other rock types are limestone and steel slag. The objective of study to determine the effect of soil type and soil distribution to porosity and CBR. At the end it can defined gradation band of every type of soil will provide maximum porosity at allowable CBR for porous pavement.

2. POROUS ASPHALT PAVEMENT STRUCTURE

The Franklin Institute in Philadelphia (1977) published a design guide for porous pavements, that has been widely referenced and provides a solid foundation for porous pavement designers. Many porous pavements have been constructed since the late 1970s.

There are some types of porous pavement such as porous asphalt pavement, porous concrete pavement, permeable interlocking concrete pavement, permeable natural stone pavement etc. In this study it concerned to porous asphalt pavement.

Porous pavement is a pavement that is constructed or created using materials that allow the flow of water infiltration into the subsoil. Mechanism the porous pavement can be shown in Fig. 1.

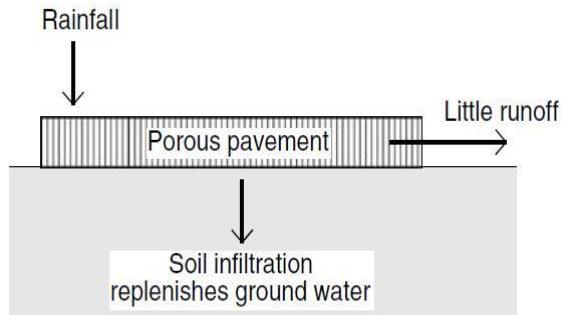


Fig. 1 Mechanism flow of rainfall in porous pavement

From bottom up the standard porous asphalt pavement consist of (Fig.2):

1. Un-compacted subgrade layer to maximize filtration.
2. Geotextile (optional) to separate between subgrade and reservoir base and prevent migration the fine aggregate from subgrade to reservoir base
3. Reservoir base is part of structural layer and temporary store rainfall water before infiltrate to the subgrade.
4. Choker coarse(optional) to stabilize the surface.
5. Open grade asphalt surface.

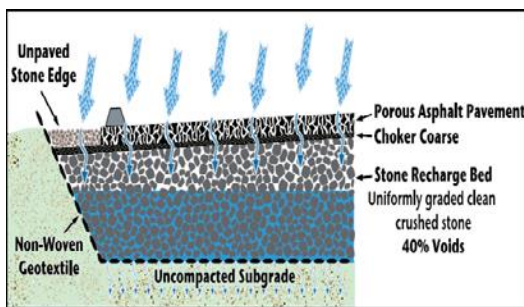


Fig.2 Porous asphalt pavement structure (NAPA)

3. GRADATION OF RESEVOIR BASE

3.1. AASHTO

Based on AASHTO (American Association of State Highway and Transportation Official) the gradation of reservoir base as Table 1.

Table 1 Soil gradation of reservoir base (AASHTO)

Size	Percent Passing, Reservoir base	
Inch (mm)	AASHTO no.3	AASHTO no.5
2 ½ (63)	100	
2 (50)	90 – 100	
1½ (37,5)	35- 70	100
1(25)	0 – 15	90 - 100
¾ (19)		20 - 55
½ (12.5)	0 - 5	0 - 10
3/8 (9.5)		0 - 5

University of New Hampshire Strom water Centre (UNHSC, 2009) recommends the aggregate gradation should meet the requirement as shown in Table 1. This specification is intended to be used for porous asphalt pavement in parking lot applications in Durham, New Hampshire. Aggregate for reservoir base needs to be clean and crushed stone. Thelen (1978) recommended the void ratio is 40%.

3.2 National Asphalt Pavement Association (NAPA)

NAPA, 1976 recommend the gradation of course for reservoir base as Table 2. The gradation is uniformly graded clean crushed stone with 40% void.

Table 2 Gradation of porous pavement NAPA (1976)

Size	Percent Passing	
Inch (mm)	Upper Limit	Lower Limit
3 (75)	100	100
2 ½ (63)	90	100
2 (50)	35	75
1½ (37,5)	0	15
¾ (19)	0	5
N0.100 (150)	0	2

3.3 Recommended Gradation of Djakfar et.al

Djakfar, Zaika, Bowoputro (2013) made gradation band for reservoir base based on 10

gradation (30 samples) of stoned crush as Table 3.

Table 3 Gradation of porous pavement of Djakfar, Zaika and Bowoputro (2013)

Size Inch (mm)	Percent Passing	
	Upper Limit	Lower Limit
2 (50)	100	100
1½ (37,5)	70	50
1 (25)	40	30
¾ (19)	30	20
0.38(9.5)	10	5
0.19(4.75)	5	0
0.08(2)	3	0

4. MATERIAL OF POROUS PAVEMENT

The material used as the porous pavement must the following criteria:

1. The material must have appropriate water storage capacity and is able to flow the water in a certain period without erosion.
2. The material must have sufficient rigidity to support traffic loading.
3. Materials should be able to get passed the impurities pavement.
4. Materials must be able to filtering and prevent shearing between the base, sub base and the subgrade.

4.1 Crushed Stone

Crushed stone or angular rock is, typically produced by mining a suitable rock deposit and breaking the removed rock down to the desired size using crushers. It is distinct from gravel which is produced by natural processes of weathering. Crushed stone is a rock that has been frequently used as a pavement because of the angle that produces high friction (interlocking), the large carrying capacity (CBR) of more than 80%, frost resistance and high bulk density .Because of crushed stone provided by nature so availability is limited so it is necessary to find alternative materials as a substitute.

4.2 Limestone

The limestone is a sedimentary rock composed of the mineral calcite and aragonite are also used as building materials and pavement. It has high CBR is around 80% but the mineral calcite in limestone dissolves easily in water depends on the temperature and acidity (pH).

Limestone reserves is very large and almost spread across the region in Indonesia. East Java is one of the major producer of limestone. The Los Angeles Abrasion of limestone is 26.6 %.

4.3 The Steel Slag

In nature, iron, copper, steel, nickel and other metals are found in impure states called ores, often oxidized and mixed in with silicates of other metals. During smelting, when the ore is exposed to high temperatures, these impurities are separated from the molten metal and can be removed. Slag is the collection of compounds that are removed. In many smelting processes, oxides are introduced to control the slag chemistry, assisting in the removal of impurities and protecting the furnace refractory lining from excessive wear. Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling.

The use of steel slag as an aggregate is considered a standard practice in many jurisdictions, with applications that include its use in granular base, embankments, engineered fill and hot mix asphalt pavement. Based on Yusof N.I.M.(2014) using steel slag for porous pavement contribute to reach high modulus resilient.

Prior to its use as a construction aggregate material, steel slag must be crushed and screened to meet the specified gradation for the particular application. Stone dust from crushed stone are used as filler in this study. Some advantages of using slag are highly angular in shape and have rough surface texture. Typical physical and mechanical properties of steel slag are shown in Table 4 and 5.

Table 4 The Physical Properties of Steel Slag

Physical properties	Value
Specific gravity	3.2 – 3.6
Unit Weight kg/m3	1600 - 1920
Absorption	< 3%

Table 5 The Mechanical Properties of Steel Slag

Mechanical properties	Value
Los Angeles Abrasion (ASTM C131), %	20-25
Angle of Internal Friction	40-50
Hardness (measured by Mohr's scale of mineral hardness)	6 – 7
California Bearing Ratio (CBR) % upper size 19 mm (3/4 inch)	>300%

In this study steel slag has 24.3 % Los Angeles Abrasion and impact is 9.49%.

Due to their high heat capacity, steel slag aggregates have been observed to retain heat considerably longer than conventional natural aggregates. The heat retention characteristics of steel slag aggregates

can be advantageous in hot mix asphalt repair work in cold weather.

5. METHODOLOGY

5.1 California Bearing Ratio (CBR)

California Bearing Ratio is comparison between stress of soil and California Stress Standard that can be wrote as Eq.(1).

$$CBR = \frac{P}{P_s} \quad (1)$$

Where:

P : stress of soil

P_s : California stress standard

Value of CBR represent quality of soil compare to stress of standard in stone crush who's CBR 100%. Standard procedure for CBR test conduct to ASTM D-1883-73 and AASHTO T-193-81. The harder material will reflect the high CBR. CBR for some type of soil material can be shown in Table 6 and for layer pavement are shown in Table 7.

Table 6 Value of CBR for Some Types of Soil Material

Material	Value of CBR(%)
Stone crush, subgrade layer	100
Natural soil aggregate as subgrade	80
Limestone	80

Table 7 CBR value for Base and Sub Base Course

	CBR in Base Course	CBR in Sub Base Course
Excellent	100	50
Good	80	40
Fair		30
Poor	50	

5.2 Porosity Test

Soil aggregate is consist of soil particle and void between particles where water and air take place. Ratio between volume of void and total volume is called porosity as shown in Eq. (2). The porosity is usually express as a percentage and influence of density of soil, higher porosity is lower density. It means easier for water to flow in soil aggregate.

The concept of porosity testing to determine the percentage of the volume of empty space with the overall volume of the mold. To find the volume of empty space filled with air can be done by filling out a certain amount of water, the amount of water taken into the void is equal to the volume of empty space filled with air cavities (Fig.3).

$$n = \frac{V_v}{V_t} \quad (2)$$

Where:

V_v : volume of void

V_t : total volume

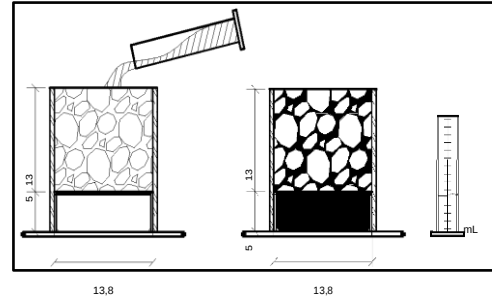


Fig. 3 Porosity Test

Some conditions will influence porosity as follows:

1. Distribution soil particle, uniformly graded soil has high porosity because volume of void bigger compare if the well graded soil.
2. Cementation of soil grand, if the soil particles have high degree cementation, the void become small and porosity is low.
3. Compaction increase the strength, lower compressibility and reduce permeability of soil by rearrange soil particle.
4. Degree of angularity, the shape individual particle is important as grain size distribution in affecting engineering response. The rounded particles have high porosity than angular.

6. SOIL GRADATION

There are 3 types (stone crush, limestone, steel slag) of soil and 7 gradation variation were prepare in this study as shown in Fig. 4.

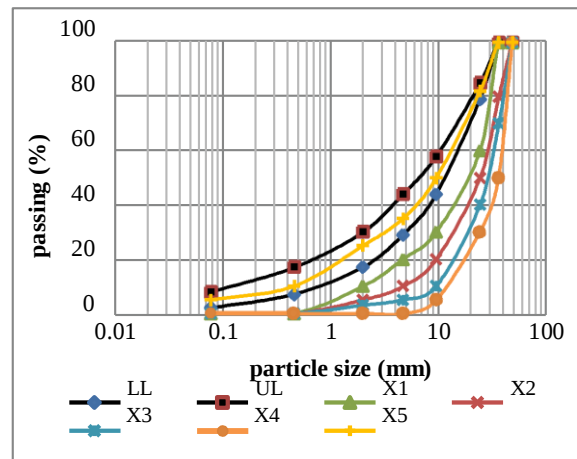


Fig. 4 Design Gradation of Experiment

The gradation X1 until X4 are course material (size more than 0.475mm). UL (upper limit), LL (lower limit) and X5 are in control gradation because it was designed in the gradation band as specified by Bina Marga.

7. RESULT AND DISCUSSION

Several tests conducted to determine the characteristics of all the soil types with variations of gradation.

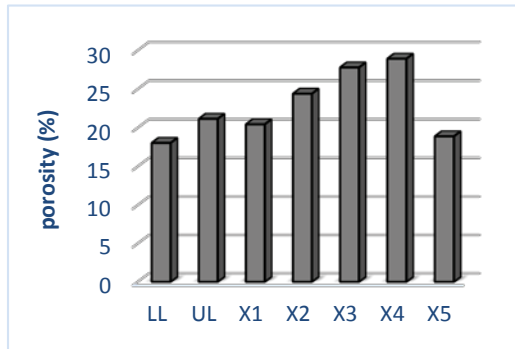


Fig. 5. Porosity of Gradation Variation of Crushed Stone

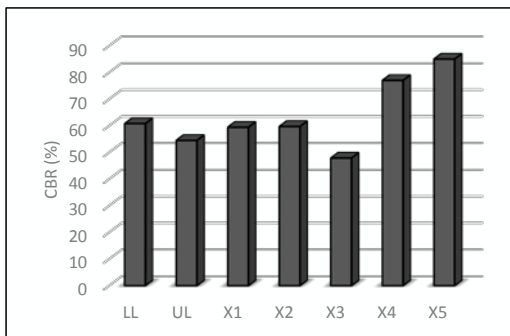


Fig. 6 CBR of Crushed Stone

The results are porosity test and California Bearing Ratio test shown in Fig.5 and 6, which is the high results of porosity is X4 and X5 for CBR value. Even in the first experiment X4 also the high value for CBR , but retests proved the X5 reach the highest one.

The limestone have the sama characteristic, which is the highest porosity value is derived from X4 gradation as shown in Fig. 7, and the highest CBR on gradation X5 (Fig.8). The gradation of X5 is gradation in specification of Bina Marga (Indonesian Highway Agency).

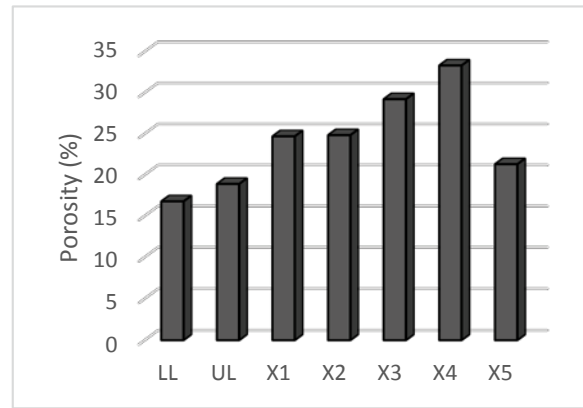


Fig. 7 Porosity of Limestone

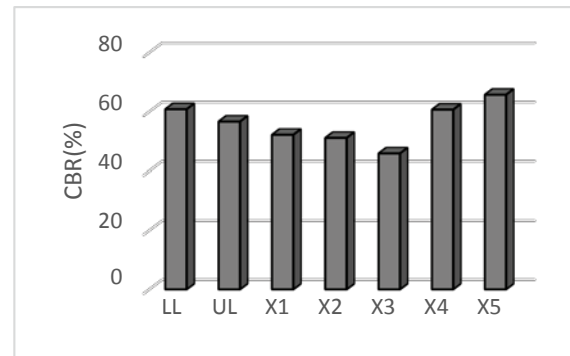


Fig. 8 California Bearing Ratio of Limestone

Due to limestone is easily soluble in water especially with high acidity, so in this study conducted CBR test in soaked conditions. The soaked CBR is lower value compare un-soaked as shown in Fig. 9.

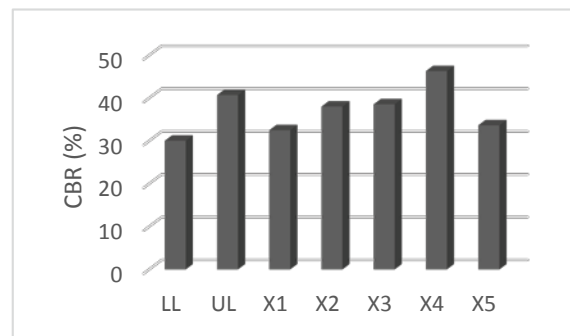


Fig. 9 Soaked California Bearing Ration of Limestone

X5 is consisting of fine material that easily dissolves when submerged in water so that the CBR is lower than X4.

Based on result of stone crush and limestone, 3 variation gradations steel slag were taken to analyses as that is X2, X4 and X5. The porosity and CBR of steel slag can be seen in Fig.10 and 11.

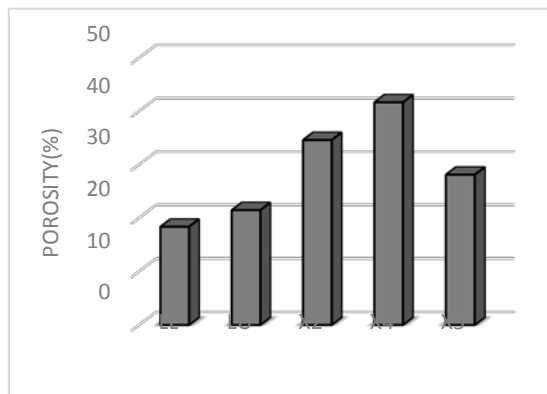


Fig.10 Porosity of Gradation Variation of Steel Slag

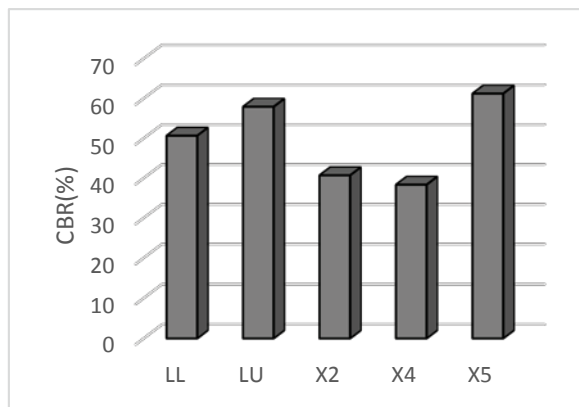


Fig.11 California Bearing Ratio of Steel Slag

From three types of soil are obtained that gradation X4 delivers maximum porosity. The number size gradation has shown that nearly uniform grain size. Based on CBR test for each trial gradation variation are obtained different results where the largest CBR value is gradation X5 showed the more dominant of the gradation.

The void ratio for coarse material (X2, X3 and X4) increase more than 100% compare to Bina Marga. Based on NAPA 1976 classification the void of porous pavement is 40%. In this case X4 have void ratio 30% to 45 %. Changing of gradation from standard one to X4 decreased CBR value 7.5 until 35%.

Based on Fig.12 gradation of X4 closed to AASHTO and NAPA specification which fit for porosity and light load traffic. In case of X5 is finer than recommended gradation but especially for crushed stone has high CBR but lower porosity.

NAPA and AASHTO gradation meet the criteria for porosity for the light traffic load and gradation based on Bina Marga has the expected carrying capacity but has lower porosity for porous pavement.

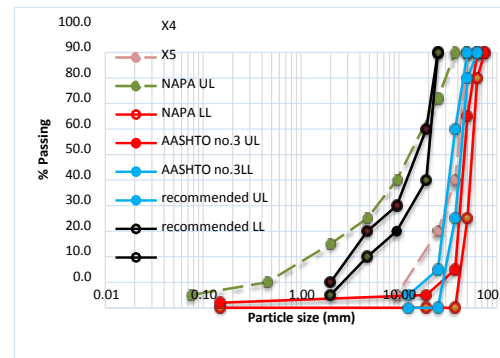


Fig 12 Comparison between AASHTO, NAPA, recommended gradation, X4 and X5

8. CONCLUSION

1. Compared with limestone and steel slag, crushed stone has a greater bearing capacity.
2. The more uniform gradation with a larger size will give high porosity. In which porosity only determined by the gradation of the mixture.
3. California Bearing Ratio of the soil depends on the hardness of the soil and gradation.
4. Despite the porous nature of the mixture as desired but the carrying capacity is only suitable for light traffic loads that require further study of material.
5. Recommended gradation is the line that is between AASHTO specifications and Bina Marga, are expected to have the requirement of porosity for porous pavement and CBR have a fairly high value.

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