Evaluation of Technical Specifications of Gradation Course Base Subdrain Layer Structure on Road

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Abstract. Subdrain layer is a type of pavement that can reduce excess water from rainwater so that it can seep into the ground. The purpose of this research is to find the relationship between the optimal water velocity to pass through the base layer and maximum carrying capacity. Sieve analysis was carried out to obtain aggregate gradation variations by modifying the Bina Marga Standards 2010. There are 5 different types of gradations used based on the reduction in the percentage of filler specifications of 8%, 5%, 4%, 3%, and 0%. Calculation of fillers is used to find out the weight of aggregate each sieve size. In addition, the compaction test was carried out on ASTM D Modified 1883 - 87 to obtain optimum water content by using from the maximum dry density curve. The results of compaction the maximum dry density varies with the range 1,911-1,981 gr/cm³. The results of the maximum dry density show that the optimum water content varies between 9-10%. Next, the test sample is reused for CBR testing which aims to determine the carrying capacity of the test sample. Results tend to decrease when the filler is reduced. Obtained CBR test results is in the range of 62-74%. The sample is reused for the infiltration test to find the speed of the water capable of passing the test sample. Based on the results of the infiltration test, the constant infiltration rate varies from 3.143 to 6.750 mm/minute. The constant speed tends to increase when the percentage of filler decreases.

Keywords: Gradation, CBR, Filler, Subdrain Layer, Compaction, Infiltration Rate

1. Introduction

Road damage is a common problem that often occurs in the rainy season. Indonesia has high rainfall so rainwater cannot flow properly because it is not supported by a good pavement structure. This causes puddles that cannot be avoided so that over time the road becomes damaged. Puddles that are above the pavement layer provide an opportunity for water to enter into the pavement layer. Water is known to be one of the causes of damage where water easily dissolves and break down materials between layers of material. Aggregate bond becomes loose due to water damage and cracks arise when the vehicle passes repeatedly [1].

Additionally, the road experiences further a decrease in structural function with increasing age and the number of heavy tonnage vehicles that cross the road [2]. Roads are damaged in a relatively short period of time from either newly built or repaired. Often road damage in Indonesia is unable to reach the age of the plan, although various efforts have been made (design, planning and maintenance) to overcome the damage to the road.[3] Based on this review, the effect of water on pavement damage
that often occurs every year, encourages various stakeholders to carry out studies related to the characteristics and movement of water on the pavement structure [4].

Puddles that occur on the road are the main cause of damage to roads [5]. This puddle is created from rainwater that cannot seep into the pavement structure. Due to the fact that it is still not optimal to overcome the puddle. One of the most effective ways is through a translucent pavement or can be of overcoming called a subdrain layer [6]. The subdrain layer is a type of pavement that allows water to pass through the pavement layer allowing the water to seep directly into the soil [7]. The subdrainage layer systems becomes a good solution for water damage road. T pavement use drain moisture materials.

The purpose of this study is to find the most optimal gradation to be used as a foundation layer using Class A Aggregates. The gradation uses was the 2010 General Specifications gradation. The results shows that 4% filler gradation was the most optimum gradation to be used as subdrain layer with CBR value 67 % and has a constant infiltration rate of 3,667 mm/ minutes. The material used is material derived from the quarry of Watukosek Village, Ngoro District, East Java which a class A aggregate materials. Based on the results of this study, the most optimal gradation to be used as a subdrain layer is a 4% filler variety with a CBR value of 67%. The chosen filler variation is a gradation that can produce a high carrying capacity and infiltration rate allowing rainwater to penetrate into the ground or not be waterproof. In this research, sieving analysis will be carried out to obtain variations of grade aggregates according to the General Specifications of div. 5 Grained Bina Marga Class A. Base material must fulfil specification requirements or perform better than other construction materials. Specification of Roads published by Bina Marga 2010 is widely used for construction purposes in Indonesia.

The design will be used to determine the time and speed of water that can flow with new gradations on the foundation layer. It is then adapted to the bearing capacity of Bina Marga’s road specification to achieve effective and durable pavement system. It is important to create material layers that allow for water to quickly and efficiently flow without moving particle materials in order to prevent premature pavement damage caused by puddle water.

2. Literature Review

Previous studies relating to scope drainage layer, subsurface drainage layer, infiltration rate, and performance of drainage layer include: thickness, type materials, aggregate gradation, and pavement camber. These studies focuses on design considerations of the base as a drainage layer which results in high strength and easily penetrable pavement structure.

Cardegen published a design guide for subdrainage pavements that has been widely used by engineers as the foundation for permeable pavement design since 1972. Cardegen’s design considers the need for a pavement subsurface drainage system. Another research by Raymond and Mirian (1996) shows that subdrainage layer can be used as pervious pavement and geotextile can replace the subdrainage layer [8]. A subdrainage layer typically contains more gravel and presents a thicker layer. It has a strong infiltration capacity.

The subdrainage layer produce a positive pavement performance, especially in its capability as drainage pavement. Several guidelines use the Cedergen model as a requirement for subdrainage layer. FHWA has given a limit and time duration for puddles enter to the subsoil. According to the Federal Highway Administration (FHWA) model, the maximum time to drain is 300 m/day and is effected by the thickness of permeable pavement. The FHWA assumes approaches for the design of subdrainage layer to remove water without allowing the system to become fully saturated.

Based on FHWA, the infiltration water into pavement is most complex. Some water assumed by Darcy’s law uses a velocity formula such as:

\[ v = k.i \]

where: v is velocity, k is constant of permeability and I is the hydraulic gradient [7]

Based on Zaika and Djakfar, the model for permeable pavement is influenced by gradation.
The gradation samples must satisfy criterias such as:
1. Base materials must have a water storage is used for entering to subsoil.
2. Base materials must have a high strength to supported load traffic.
3. Base materials must be able passed by water.
4. Materials must be able to strain so that subgrade, subbase and surface can be intact [9]

According to Integrated Corridor Management (ICM), the base course pavement is influenced by temperature of moisture content. The temperature element is one of the analysis for the design of drainage layer. Additionally, drainage layer also depends on the duration of rainfall to distribute the water into the pavement’s structure. Materials with different combination such as fewer fines and more uniform aggregate and different size aggregates have shown to have higher infiltration rate.

3. Method
In this study using several stages of research. The research stage is used as the basic concept of development in facilitating the research process until to data analysis. First, base material was prepared by sieving analysis. Sieve analysis, CBR, MDD, OMC and Infiltration rate values were obtained for this base material. A stock of filler particles was prepared by sieving a soil through No. 200 sieve. These sieved filler were incrementally added to the prepared base material to make 5 different variation soil samples. All tests relevant to base materials were preformed to each of these prepared samples.

3.1 Materials
Crushed stone aggregate taken from Watukosek Village, Mojokerto City were used in this study as aggregate Claas A. Standard ASTM C 136 was used to make grading of materials proposed for use as aggregate. The method was used to determine the grading of materials for use as subdrainage layer. The aggregate were dried at temperature of sunlight. When using sieve analysis, aggregate class A were retained for percentage passing and percentage retained were calculated. Specification of Bina Marga 2010 have limitations on the maximum and minimum recommended particle size exist. Aggregate Class A is typically produced by natural process and used as a pavement because of that materials have high permeability.

3.2 Sieve Analysis
The sieve used is size number 1.5;1; 3/8;4; 10;40; 200. The purpose of sieve analysis is to obtain gradations of the test sample to be used. Sieved test materials using mechanical vibration machines where the sieve holes are smaller in sequence. In order for the sample to be representative, approximately 6 kg of each materials sample was taken for sieve analysis.

3.3 Compaction Test of Sample
Compaction of the base course is one of the important proses for construction of any types of pavement. At the beginning of the compaction process, the dry volume weight increases with increasing water content [10]. When the water content is gradually added with the same compaction effort, the weight of the soil grains also increases. At water levels greater than certain water levels, the water content becomes optimum and the increase in water actually reduces the weight of the dry volume. The relationship between the weight of the dry volume and the weight of the soil and water content depends on the effort given by the pounder. This research uses a Modified Proctor to determine the characteristics of its material density.

Compaction test is provide the determining water content which is selected in five layers into mold of given dimensions. Materials compacted by 56 blows with the hammer. Water content is to determine the relationship between dry unit weight and water content for the materials the result must be plotted, represents Optimum Water content and Maximum Dry Densitiy. Figure 1 shows the the OMC change according to MDD.
3.4 California Bearing Ratio
Various material preparations and test equipment refer to ASTM D 1883 specifications. This method is used to determine the potential strength of base course material for use in road pavement. In this research CBR testing was soaked. CBR in soaked condition is needed to know the performance of pavement the saturated materials condition. CBR values are values that state the quality of a material at the same penetration. Preparation and CBR test equipment refers to the ASTM D1883 standard. In this study using CBR soaked for 4x24 hours. Reading the proving ring for 10 minutes. The result of these tests are shown in Table 4.3. The quality and consistency are needed to determine the properties of base materials.

California Bearig Ratio is equation to compare stress of materials and depth penetration. Value of CBR shows strength of soils and CBR standard. Based on specification of Bina Marga 2010, the standard of values CBR is 90%. The formula to determine the value of can be shown as Eq. (1)

\[ CBR = \frac{p}{P_s} \]  

Where;
- \( P \) : stress of materials
- \( P_s \) : California stress standard [11].

3.5 Infiltration Test
The infiltration test is used to determine the speed of water that can penetrate the test object. The test object used is a test object that has been compacted with the same optimum water content during the CBR test. Modified CBR has a pore on the bottom cover that functions as a water way out of the test object. Water reduction every 60 seconds is calculated and recorded. The falling water flow starts to be calculated using a stopwatch. The treatment of infiltration testing on other gradations remains the same.

3.6 Sample Test
The material sample tested in this research is a base course A material that comes from the quarry of Watukosek Village, Nguro District, East Java.

3.7 Material Mixing Method
This material uses a method of reducing filler material in the DGH 2010 gradation. Filler reduction is based on the upper specifications and middle specifications, namely 8%, 5%, 4%, 3% and 0%. Based on table 4.1, the percentage of the sieve sizes shown after the filler reduction is shown. The purpose of this modification is to obtain a variable CBR value and infiltration rate so that the most optimal gradation is obtained in the subdrain layer. Finding approved base materials with varied percentages of filler is difficult. Therefore, it was decided to prepare soil samples, with satisfy all the Bina Marga Spesification Base material requirement.
Table 1 Variations in Subdrain Layer Research.

| Sieve Number | Sieve Size (mm) | Bottom Specification | Top Specification | Sample 1 % Passing | Sample 2 % Passing | Sample 3 % Passing | Sample 4 % Passing | Sample 5 % Passing |
|--------------|----------------|----------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| 2"           | 50             | 100                  | 100               | 100.00            | 100.00            | 100.00            | 100.00            | 100.00            |
| 1"1/2"       | 37.5           | 100                  | 100               | 100.00            | 100.00            | 100.00            | 100.00            | 100.00            |
| 1"           | 25.0           | 79                   | 85                | 85.00             | 82.00             | 84.35             | 81.62             | 81.05             |
| 3/8"         | 9.50           | 44                   | 58                | 58.00             | 51.00             | 56.17             | 49.97             | 48.42             |
| No. 4        | 4.75           | 29                   | 44                | 44.00             | 36.50             | 41.57             | 35.16             | 33.16             |
| No.10        | 2.0            | 17                   | 30                | 30.00             | 23.50             | 26.96             | 21.89             | 19.47             |
| No.40        | 0.425          | 7                    | 18                | 17.00             | 12.00             | 13.39             | 10.15             | 7.37              |
| No.200       | 0.075          | 2                    | 8                 | 8.00              | 5.00              | 4.00              | 3.00              | 0.00              |
| Filler       | 0              | 0                    | 0                 | 0.00              | 0.00              | 0.00              | 0.00              | 0.00              |

Figure 1. Particle size distribution curves of considered gradations from Table 1

4. Result and Discussion

4.1 Maximum Dry density (MDD)

Figure 2 shows the highest maximum dry weight of 8% filler gradation. The maximum dry density and the optimum water content of the base materials samples were measured and shown with the compaction curve. The results of density testing are shown in figure 2 shows the maximum dry weight and optimum water content. From the figure is found that with a decrease filler in compaction the values of MDD decrease.
4.2 California Bearing Ratio

In this paper we looked at the effect of filler percentage on CBR values due to a reduction in the percentage of filler into the subdrain layer. The CBR uses a proving ring reading with a maximum load of 7.492 lbs for 1 dvs or equivalent to 3.358 kg and the volume of CBR molds used is 2140.9 cm³. Tables 2 presents the result of CBR test in soaked condition. For each effect of filler samples were tested and performed load versus penetration curve have been calculated.

Figure 3 shows the CBR graph of all the gradations that have been subtracted based on the gradation characteristics based on the reduction in the percentage of filler. CBR values for each sample vary. This is because filler as a filler is getting smaller. Based on the graph it can be concluded that the percentage of filler decreases, the CBR value will decrease. Based on the test results, it is known that the maximum CBR that can be obtained from the percentage of filler is 74.654% for 4 days CBR immersion. The gradation is the strongest to withstand the road load for the subrain layer foundation. Relationship of Gradation of Aggregates with CBR values. The relationship between filler reduction and gradation can be seen in Figure 4. The percentage of fillers is arranged by the largest percentage of 8%, 5%, 4%, 3% and 0%

| Filler Percentage | Optimum Water Content (%) | Maximum Dry Density (maks. gr/cm³) | CBR Value (%) |
|-------------------|--------------------------|-----------------------------------|---------------|
| 8%                | 9.00                     | 1.981                             | 74.654        |
| 5%                | 9.00                     | 1.977                             | 65.598        |
| 4%                | 10.00                    | 1.939                             | 67.345        |
| 3%                | 11.00                    | 1.915                             | 63.763        |
| 0%                | 9.00                     | 1.929                             | 62.400        |

Figure 2. Relationship between MDD and Filler Percentage
Based on Figure 2, it can be seen that the highest CBR value is in the 8% filler, which is 74.54%. This is because the percentage of fillers possessed by these gradations is the largest and has the best density, because the fillers fill empty cavities between coarse and fine aggregates. However, this gradation is the most watertight gradation. Analyzing these results clearly reveals that filler percentage has a close relationship to the bearing strength of the material. 4% filler gradation is the most optimum gradation because it has the optimum CBR because it has the most varied coarse and fine aggregate percentage.

4.3 Correlation of Aggregate Gradation to Infiltration Rate

The infiltration rate aims to determine the speed of water that can pass through a sample. In this research the test sample used was granular material, so the infiltration method was used. The infiltration rate test results are presented in Table 3.

| Filler Percentage | Steady Infiltration Rate (mm/menit) |
|-------------------|-------------------------------------|
| 8%                | 3,200                               |
| 5%                | 3,667                               |
| 4%                | 4,000                               |
| 3%                | 4,667                               |
| 0%                | 6,750                               |

\[ y = 149.55x + 60.77 \]
\[ R^2 = 0.8267 \]

Figure 3. Graph of Filler Relationships with CBR

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From figure 4, it can be seen the relationship between the characteristics of the filler reduction gradation, it can be concluded that the more fillers the infiltration rate decreases or in other words it reduces the speed of water flow. This is because the air cavity is filled with filler. Analyzing these results clearly reveals that filler percentage has a close relationship to infiltration rate of the material. In this study the highest infiltration rate was obtained at 0% filler variation which is the smallest aggregate filler gradation and has a larger cavity so that the water is easily flowed as high as having a high infiltration rate.

### 4.4 CBR Relationship with Infiltration Rate

Based on the 5 gradations taken aiming to obtain the maximum CBR value. Five gradations consisting of 8%, 5%, 4%, 3%, 0% filler are gradations within DGH. The purpose of determining this gradation is to get the maximum CBR and have the optimum infiltration rate so that the foundation layer results that function as a subdrain.

**Table 4. Relationship between CBR Value and Infiltration Rate in the research**

| Percentage (%) | CBR Value (gr/cm3) | Infiltration Rate constant (mm/minutes) |
|----------------|---------------------|----------------------------------------|
| 8%             | 74,654              | 3,200                                  |
| 5%             | 65,598              | 3,667                                  |
| 4%             | 67,345              | 4,000                                  |
| 3%             | 63,763              | 4,667                                  |
| 0%             | 62,400              | 6,750                                  |
In this research using a proofing ring with a maximum load of 10,000 lbs with a calibration factor of 7.492 lbs for 1 reading of the proving ring or equivalent to 3.358 kg.

The calculation method is in accordance with the calculation of laboratory CBR values which generally use the graph method to calculate the CBR value. Analyzing these results clearly reveals that filler percentage has a close relationship to infiltration rate of the material. Infiltration Rate (gr/cm³)

Figure 5. Graph of CBR Value Relationships with Infiltration Rate

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In table 6 shows the relationship between CBR value and infiltration rate. It can be seen that the greater the CBR value, the lower the infiltration rate is constant. This shows that the maximum CBR has more fine grains so that the ability of water to pass through a sample is slower. Meanwhile, if it has a low CBR, it has fewer fine grains so that the infiltration rate becomes faster.

Besides being influenced by the filler percentage, CBR values are also influenced by the strength of the granules. If the sample mixes with water, the aggregate will decrease due to the flow of water so that the pores in the specimen increase and decrease the CBR value.

Based on the results of the infiltration and CBR tests, the gradation that is considered to be used as the subrain foundation layer is a percentage of 4%. The consideration taken is to have a high CBR and an optimal infiltration rate of 74.654% and 4,000 mm / minute.

5. Conclusion

1. The gradations used are Bina Marga Class A, fillers 8%, 5%, 4%, 3% and 0% are gradation references by reducing the percentage of filler that has been distributed.
2. The more filler percentage in a feeding gradation the infiltration rate becomes more impermeable, the water passing through the specimen becomes slowed. If the percentage of filler is smaller than the infiltration rate is getting bigger.
3. In the relationship graph of the gradation with CBR values shows that the 8% filler is 74.56% is the gradation that has the highest CBR because it has the most fillers. While the lowest CBR is in the 0% filler, which is 62.44%.
4. From the results obtained according to the infiltration rate and CBR values, the gradation that qualify for the subrain foundation layer is a 4% filler gradation because it has a fast infiltration rate and maximum CBR value.

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