Permeability analysis of Asbuton material used as core layers of water resistance in the body of dam

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Abstract. In order to increase consumption of the local materials and national products, large reserves of Asbuton material about 662.960 million tons in the Buton Islands became an alternative as a waterproof core layer in the body of dam. The Asbuton material was used in this research is Lawele Granular Asphalt (LGA). This study was an experimental study conducted in the laboratory by conducting density testing (content weight) and permeability on Asbuton material. Testing of the Asbuton material used Falling Head method to find out the permeability value of Asbuton material. The data of test result to be analyzed are the relation between compaction energy and density value also relation between density value and permeability value of Asbuton material. The result shows that increases the number of blow apply to the Asbuton material at each layer will increase the density of the Asbuton material. The density value of Asbuton material that satisfies the requirements for use as an impermeable core layer in the dam body is 1.53 grams/cm³. The increase the density value (the weight of the contents) of the Asbuton material will reduce its permeability value of the Asbuton material.

1. Introduction
One of the main government programs is food sovereignty by construct 65 dams across Indonesia within 5 years, establishing a 1 million hectare irrigation network and rehabilitating an irrigation network of 3 million hectares, and encouraging the use of local products domestically. Serious research shall be conducted to find the dam type which more efficient, easier in operation maintenance, more resistance to disaster risk, easy in material availability. In Indonesia, the existing dams are generally embankment type. Embankment type dam is divided into three types, namely: homogeneous embankment, embankment type zonal and embankment membrane type [1]. Embankment Dam homogeneous, the former material of the dam body is the soil. Embankment Dam type zonal, material forming the body of the dam consists of several types of materials such as permeable materials and waterproof materials in the middle[2]. Material for Zonal-type embankment dam mostly using rock (big stone) as major component for dam stabilization. Waterproof layer will be installed on the upper stream or inside the body of the dam as core layer to preventing water penetrate through dam body. In general, the waterproof material used in Indonesia is clay, while abroad besides clay is also used as concrete asphalt mixture (hotmix)[3-4].

Indonesia reserve very large natural asphalt called Aspal buton (Asbuton) in Buton Island Southeast Sulawesi Province (figure 1). Based on assessment conducted by the Alberta Research Council on the 1980s and validated by The Pusjatan, Ministry of Public Works in 2010-2013 around
662,960 million tons [5]. Several studies showed that most of physical properties of bitumen within Asbuton similar with the petroleum bitumen [6-8]. The excess of asphalt-containing materials compared to clay soils used as a watertight core layer in a zonal type strain [9], is as follows:
- The risk of leakage is less likely
- The risk if there is a smaller earthquake.
- Shorter construction time.
- Maintenance is easier.

Based on the reasons mentioned above, the author intends to conduct research on "Permeability Analysis of Asbuton Material Used As A Waterproof Core Layer On The Body of Dam".

Figure 1. Asbuton mining in Buton Island, Indonesia (natural rock asphalt)

2. Theoretical basis

2.1. Asbuton granule for waterproof zone material
Grain Asbuton is the result of the processing of solid-shaped Asbutons crushed by a stone crusher or other suitable cracking device having a specific grain size. The raw material to produce grain Asbuton can be obtained from solid Asbuton chunks.

2.2. Permeability testing
The permeability test is the most important test on material samples for dams. The permeability level of a material is usually characterized by a coefficient of permeability or filtration coefficient of cm/s. One of permeability testing in laboratory based on simple theory is relation between velocity of water through pores of the soil and hydraulic gradient, where flow of water through soil pores is laminar. Darcy formula raised up based on mentioned phenomenon, as follows;

\[ Q = K i A \]  

where:
- Q is the discharge flowing through the cross-section unit per unit time (cm³/s), I is hydraulic gradient, K is filtration coefficient (cm/s), A is cross section (cm²).

In this formula, it is considered that water flows through the entire cross section (A), so not through the pores of the soil. In general, the level of permeability of soil materials has been grouped as follows:
- Pass water (permeable), \( K > 10^4 \) (cm/s)
- Semi-water pass (semi-permeable), \( K = 10^4 \) (cm/s)
• Waterproof (impermeable), K < 10^{-4} (cm/s)

The Darcy formula can only be used in slow laminar slow filtration flow, while for high-speed turbulent flow, the Darcy formula cannot be applied. Therefore, soil permeability testing should be carried out in laminar flow, so that the obtained filtration coefficient only gives identity to laminar flow because turbulent flow cannot occur on fine grained soils such as in clays and silt, so for the soil type, the Darcy formula is sufficient.

• Testing permeability with variable water level elevation. This test is carried out with examples of materials that are expected to have low permeability. The coefficient of filtration of the material sample can be calculated by using the following formula:

\[
K = 2.3 \left( \frac{aL}{At} \right) \log_{10} \left( \frac{h_0}{h_t} \right)
\]

where, K is coefficient of filtration (cm/s), T is duration of measurement (s), A is cross section of the material sample (cm²), a is cross section of the pipe (cm²), L is thickness of the material sample (cm), H₀ is the water level in the pipe at the start of the test (cm), Hₜ is the water level in the pipe at the end of the test (cm).[10]

2.3. Core layer density

One of the factors that support the strength and stability of the dam body is adequate compaction. The density of a material greatly affects the mechanical characteristics of the material, particularly the weight of the contents, permeability, stability and others. The most important factors affecting the level of compaction of the material is the water content, gradation and the amount of energy given to the compaction of the material. In essence the compaction of the material is essential effort to remove the air from the gaps between the grains of material.

The parameters associated with the density are as follows:

\[
W = \left( \frac{W_w - W_{d}}{W_d - W_c} \right) \times 100\%
\]

\[
\gamma_d = \frac{\gamma_w}{(w + 100)} \times 100\%
\]

\[
\gamma_d = \frac{100G_s}{(100 + wG_s)}
\]

where, W is water content (%), w is moisture content (%), Wₜ is weight of wet test object and container (gram), Wₜ is weight of dry specimen and container (gram), Wₚ is weight of container (gram), \( \gamma_d \) is dry fill weight (gram/cm³), \( \gamma_w \) = wet content weight (gram/cm³), Gₛ is material density.

While the number of blow indicates the amount of energy given in the compaction process. If given energies to the material are increased, the weight of the dry content will be increased, while the optimum water content will move in a drier direction.

The amount of energy given when carrying out the compaction of the material, it can be calculated by the following formula.

\[
E_c = \frac{W.H.N.L}{V}
\]

Where, \( E_c \) is amount of compaction energy (kg/cm³), W is weight of hammer (kg), H is high falls hammer (cm), N = collision frequency at each layer, L = number of layers, V = print volume (cm³).[10].
3. Research methodology

3.1. Research design
The research flowchart can be seen on figure 2. The testing methods performed in this study are based on the Indonesian National Standard (SNI). Other standards such as the American Association of State Highways and Transportation Officials (AASHTO) and American Society for Testing and Materials (ASTM) are used if no available in SNI.

3.2. Testing of Asbuton Material Density
The density testing procedure of Asbuton material refers to SNI 03-1743-1989 [11]. The pounder used weighs 4.54 kg with a falling height of 45.7 cm. Diameter of mold 152 mm with 116 mm height and volume is 2124 cm$^3$. The number of layers were 5, each layer was blowed 56 times according to the standard, but in this research the relationship between the density value and the blow energy per layer was considered.

3.3 Testing of Permeability of Asbuton Materials
The testing procedure for permeability of Asbuton material refers to ASTM D 2434-68 [12]. The permeability test uses the falling head method, because the material to be tested is estimated to have low permeability.

![Flowchart of research design](image)

Figure 2. Flowchart of research design

4. Result and analysis

4.1. Data presentation

4.1.1. Test of result of Asbuton material density
The results of density testing of Asbuton material to be used as a watertight core layer in the dam body can be seen in Table 1.
Table 1. Test result of Asbuton material density

| Energy of Compaction (kg/cm²) | Density Value (gram/cm³) |
|------------------------------|--------------------------|
| 27.35                        | 1.24                     |
| 34.19                        | 1.40                     |
| 41.52                        | 1.51                     |
| 48.84                        | 1.53                     |
| 67.17                        | 1.55                     |

4.1.2. Testing result of Asbuton material permeability

The results of the permeability testing of Asbuton material to be used as a watertight core layer in the dam body can be seen in Table 2.

Table 2. Test result of Asbuton material permeability

| Density Value (gram/cm³) | Permeability Value (cm/s) (gram/s) |
|--------------------------|-----------------------------------|
| 1.24                     | 2.12 x 10⁻³                       |
| 1.40                     | 1.86 x 10⁻⁴                       |
| 1.51                     | 4.19 x 10⁻⁵                       |
| 1.53                     | 1.12 x 10⁻⁶                       |
| 1.55                     | 7.33 x 10⁻⁶                       |

4.2. Data analysis

The density test data the permeability testing of Asbuton material will be analyzed by correlating the number of compactions per layer with density value and the relationship between the density value and the permeability value.

4.2.1. Relationship between density value energy compaction

The relationship between compaction energy and the density value of Asbuton material can be seen in figure 3. Density value increase parallel with compaction energy given, indicating that increases number of blow will create denser and heavier Asbuton. The relationship between the compaction energy and the density value of the Asbuton material is illustrated in the equation:

\[ \gamma = -0.0005E_c^2 + 0.0541E_c + 0.1579 \]  

where, \( \gamma \) is density value (gr/cm³) and \( E_c \) is energy compaction (kg/cm²)
4.2.2. Relationship between density value with permeability value

The permeability value for the impermeable core coating material does not exceed $10^{-5}$ cm/s. Table 2 shows that the density value of the Asbuton material that meets the requirements for use as an impermeable core layer in the dam body is 1.53 gr/cm$^3$. The relationship between density value and the permeability value of Asbuton material can be seen on figure 4.

Figure 4 shows that the permeability value of Asbuton will decrease when the value of density is increased, indicating that pores in the Asbuton will be less in the denser Asbuton. With the smaller pores in the Asbuton material, the volume of water passing through the pores is getting smaller. The relationship between the density value and the permeability value of the Asbuton material is illustrated in the equation:

$$ K = 0.0061\gamma^2 - 0.0241\gamma + 0.0226 $$

(8)

where, $K$ is permeability value, cm/s, $\gamma$ is density value, gram/cm$^3$
5. Conclusions and suggestions

5.1. Conclusions
Based on the results of research and data analysis, it can be concluded as follows:

- Applying greater compacting energy on the Asbuton material in each layer will create higher density of the Asbuton material. Compacting energy applied to the Asbuton material in each layer, the higher the density (weight) of the Asbuton material.
- The density value (weight of contents) of Asbuton material that satisfies the requirements of impermeable core layer in the dam body is 1.53 gr/cm³. The higher density value (weight of content) of the Asbuton material opposites with the permeability value of the Asbuton material.

5.2. Suggestions
For further research development, we suggest some suggestions as follows:

- Still needed research to determine the durability of Asbuton material after submerged water.
- Make a modeling to find out the effective width of the Asbuton which can be used for impermeable core layer in the dam body.

6. References
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