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Effectiveness of Asbuton as the Core of the Dam

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Abstract: In order to increase the use of domestic materials asbuton material is an alternative choice for use as a watertight core layer on the dam body. The experimental data to be analyzed is the relationship between the permeability coefficient value with asbuton thickness. The influence of water pressure and the relationship between the permeability coefficient value with asbuton thickness due to the influence of water pressure to get the thickness design model of the core layer. The results showed that the ratio between asbuton thickness and water level of the dam at the permeability test without influence of water pressure was 1/100 while the influence of maximum water pressure was 1/20. The thickness design model of core layer using asbuton is on upper surface layer 1/100 and base 1/20 of dam water level.

Key words: Asbuton, permeability, water pressure, thickness of core layer, dam, thickness

INTRODUCTION

One of main program of Indonesia government today is food sovereignty. To pursue the program, Public Work and Housing Ministry build 65 dams whole Indonesia within 5 years, build a 1 mil.ha irrigation channel, rehabilitate irrigation channel of 3 million ha and encourage the use of local products domestically. In order to support the program, researches on innovations of dam types for more economical, easier to implement and maintain, safer to disaster risks and easy access to materials needed.

In Indonesia, the existing dam is generally embankment dam type. Embankment dam type is divided into three types, namely: homogeneous, zonal and membrane type. For a homogeneous dam, the dominant material of the dam is the soil. A zonal dam, material forming of the dam consists of several types of materials, water pass (porous) and waterproof materials. Membrane dam is an embankment dam with water pass (porous) material while the upstream is seated with waterproof layer.

The zonal type is the embankment dam which most of material of dams are stones, that serve as a major supporter of dam stability. For water-resistant zones, a waterproof layer is installed with a waterproof membrane upstream of the upper slopes or inside the dam body in the form of a waterproof core layer. Generally, the waterproof material using in Indonesia is clay. While in an abroad, besides clay is used as concrete asphalt mix (hotmix) also (Akhtarpour and Khodaii, 2014; Anonymous, 2011a-c, 2015; Budiamin *et al*., 2015).

Indonesia has a very large natural asphalt rock reserve which is asphalt buton (asbuton) in Buton Island Southeast Sulawesi Province. The reserves of asbuton material according to an assessment undertaken by the Alberta Research Council in the 1980s and validated by the Pusjatan Ministry of Public Works in 2010-2013 amounted to 662.960 million tons. Estimated asbuton deposit can be seen in Table 1, deposit asbuton as shown in Fig. 1 and taking asbuton as shown in Fig. 2.

Tabel 1: Estimated asbuton deposit

Location	Luas (m^2)	Tebal (m)	Deposit (ton)
Rongi	57.755.000	78	226.165.670
Kabungka	181.004.200	78	312.718.460
Lawele	130.906.500	78	99.786.080
Epe	1.720.000	78	2.011.157
Rota	4.530.000	78	19.596.780
Madullah	620.000	78	2.682.120
Total	376.537.850		662.960.267

Pusjatan PU (2014)

Fig. 1: Asbuton deposit at Lawele

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Fig. 2: Taking asbuton at Lawele

The advantage of asphalt-containing materials compared to clay soils used as a watertight core layer in the zonal type constellation as follows:

- The risk of leakage is less
- The risk is smaller if there is an earthquake
- Shorter construction time
- Maintenance is easier

MATERIALS AND METHODS

Granular asbuton for core layer material: Grain asbuton is the result of the processing of solid-shaped asbutons that are broken with a stone crusher or other suitable cracker, to be a specific grain size. The raw material for making grain asbuton can be obtained from solid asbuton chunks. Through this treatment is expected to eliminate the weaknesses of asbuton use, so far, namely the uniformity of bitumen content and water content by making a finer grain size, furthermore, it simplifies the mobilized of asbuton bitumen from the mineral grains. Grain asbuton to be used should be in packing bags or other containers that are water-resistant. The asbuton of the grain should be placed in a dry, roofed place to protect asbuton from rain and direct sunlight. The height of accumulation of grain asbuton shall not exceed 2 m (Moayed *et al*., 2011; Narita, 2000; Rahim *et al*., 2017a, b, 2018; Shafiei anf Eskandari, 2016; Soedibyo, 193).

Core layer permeability: Permeability is defined as the nature of the porous material that allows fluid to flow through the cavity. The permeability level of a material is usually characterized by a coefficient of permeability or filtration coefficient of cm/s. To obtain the permeability coefficient, the material is usually tested in the laboratory or tested in its original condition in the field.

How to test permeability in the laboratory is based on Darcy's theory. This theory is based on the relationship between the velocity of the water flow through the material pores and the hydraulic gradient where the flow of water through the pores is considered to be laminar. Based on the phenomenon, Darcy created a formula is called the Darcy formula as follows:

$$Q = K_i A \tag{1}$$

Where:

Q = The discharge flowing through the cross-sectional unit (cm^3/sec)
i = The hydraulic gradient
K = The coefficient of permeability (cm/sec)
A = The cross section (cm^2)

Based on the magnitude of the permeability coefficient, the level of permeability of materials is divided into three groups, namely:
Water pass (permeable):

$$K>1\times10^{-4}\ (cm/sec)$$

Semi-water pass (semi-permeable):

$$K = 1\times10^{-4}\ (cm/sec)$$

Impermeable:

$$K<1\times10^{-4}\ (cm/sec)$$

While the permeability coefficient value of the eligible material for the core layer is $K<1\times10^{-4}$ (cm/sec). Laboratory permeability testing is done in two ways, namely constant water level elevation (constant head) and the way of variable water level elevation (falling head).

The permeability test with constant water level elevation was performed for samples of high permeability estimated material and a tool using a manometer tube (pressure). The formula used to calculate the permeability coefficient value at constant surface elevation is as follows:

$$K = \frac{VL}{tAh} \tag{2}$$

Where:

K = The coefficient of permeability/hydraulic conductivity (cm/sec)
V = The Volume of running water (cm^3)
L = The thick of sample material (cm)
t = Measurement time (sec)
A = The cross section (cm^2)
h = The water level difference (cm)

The permeability test with variable air surface elevation is performed for samples of material which is estimated to be low permeability. The formula used to calculate the permeability coefficient on the air variable surface elevation is as follows:

$$K = 2.3\left(\frac{aL}{At}\right)\log 10\left(\frac{h_0}{h_1}\right) \quad (3)$$

Where:
K = The coefficient of permeability (cm/sec)
a = The cross section of the pipe (cm^2)
L = The thick sample material (cm)
A = The cross section (cm^2)
t = The measurement time (sec)
h_0 = The water level in the pipe at the start of the test (cm)
h_1 = The water level in the pipe at the end of the test (cm)

Core layer density: One of the factors that support the strength and stability of the dam body is adequated 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 essensial effort to remove the air from the gaps between the grains of material. The parameters associated with the density are as follows:

$$W = \left[\frac{Ww - Wd}{Wd - Wc}\right] \times 100\%$$

$$\gamma d = \left[\frac{\gamma}{w + 100}\right] \times 100\%$$

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:

$$E_c = \frac{WHNL}{V}$$

Where:
E_c = Amount of compaction energy (kg/cm^2)
W = Weight of hammer (kg)
H = High falls hammer (cm)
N = Collision frequency at each layer
L = Number of Layers
V = Print Volume (cm^3)

Thickness of the core layer: The determination of the thickness of the core layer is based on technical and economic considerations. The thickness of the core layer has a minimum limit. The minimum boundary of the core layer is influenced by several factors as follows:

- Water filtration capacity (permeability coefficient) permitted to flow through the core layer
- Dimensions (thickness and height) of the core layer
- The difference of plasticity and gradation between the material of the core layer and the materials in the zones adjacent to the core layer

The observation of the dam that has been built which a core layer with a thickness of 30-50% of the water pressure working on the core layer was generally sufficient to function properly in the worst conditions.

The water pressure working on the dam according to the coulomb way is expressed in the equation:

$$P_a = 1/2\gamma K_a H_2$$

Where:
P_a = The water Pressure (kg/cm^2)
H = The water level (m)
γ = The weight of water content = 1 (g/cm^3)
K_a = The active coefficient of water = 1

RESULTS AND DISCUSSION

Data presentation

Asbuton thickness test results without water pressure effect: The test results of the seepage time with the thickness of asbuton used as the core layer of the dam body can be seen in Table 2.

While the test results of permeability coefficient value to asbuton thickness without influence of water pressure with comparison between asbuton thickness and water level 1/100 can be seen in Table 3.

Table 2: The seepage time with the thickness of asbuton

Description/Units	Values					
Asbuton (cm) thickness	2	4	6	8	10	12
Seepage time (sec)	1088	2441	3531	4770	6690	8190

Table 3: Coef permeability with asbuton thickness without water pressure effect

Description/Units	Values					
Asbuton (cm) thickness	2	4	6	8	10	12
Coef. (cm/sec) Permeability	8.92 E-06	7.94 E-06	8.24 E-06	8.12 E-06	7.24 E-06	7.10 E-06

Table 4: Coef of permeability with water pressure on asbuton thickness 2 cm

Description/Units	Values				
Thick/ (cm)	2.00	2.00	2.00	2.00	2.00
Water (kg/cm^2)	1.00	0.90	0.80	0.70	0.60
pressure					
High (cm)	44.72	42.43	40.00	37.42	34.64
Thick high	1: 22.36	1:21.21	1:20.00	1:18.17	1:17.32
Coef. (cm/sec)	9.63	2.05	8.52	3.56	2.25
Permeability	E-05	E-05	E-06	E-06	E-06

Table 5: Coef of permeability with water pressure on asbuton thickness 4 cm

Description/Units	Values				
Thick (cm)	4.00	4.00	4.00	4.00	4.00
Water (kg/cm^2)	4.00	3.60	3.20	2.80	2.40
pressure					
High (cm)	89.44	84.85	8.00	74.83	69.28
Thick high	1:22.36	1:21.21	1:20.00	1:18.17	1:17.32
Coef. (cm/sec)	7.95	6.91	8.15	2.19	1.15
Permeability	E-05	E-05	E-05	E-05	E-05

Table 6: Coef of permeability with water pressure on asbuton thickness 6 cm

Description/Units	Values				
Thick (cm)	6:00	6:00	6:00	6:00	6:00
Water (kg/cm^2)	9.00	8.10	7.20	6.30	5.40
pressure					
High (cm)	134.16	127.28	120.00	112.25	103.92
Thick high	1:22.36	1:21.21	1:20.00	1:18.17	1:17.72
Coef. (cm/sec)	3.86	6.36	7.58	2.05	9.72
Permeability	E-04	E-05	E-06	E-06	E-07

Asbuton thickness test result due effect of water pressure: The test results of the permeability coefficient of water pressure on 2 cm asbuton thickness can be seen in Table 4.

The test results of the permeability coefficient of water pressure on 4 cm asbuton thickness can be seen in Table 5.

The test results of the permeability coefficient of water pressure on 6 cm asbuton thickness can be seen in Table 6.

While the test results of permeability coefficient value to asbuton thickness due to influence of water pressure with comparison between asbuton thickness and water level 1/20 can be seen in Table 7 (Soltani and Lithouuki, 2010; Sosrodassono and Takeda, 2016; Sabagio *et al*., 2003; Tjaroge *et al*., 2015; Wesly, 2010).

Data analysis

Analysis of asbuton thickness test without water pressure effect: The test data of the seepage time with the asbuton thickness will be analyzed by connecting the time of seepage to the thickness of the asbuton as shown in Fig. 3.

Figure 3 shows that the thicker the asbuton material, the longer the seepage time. This happens because the thicker the asbuton material, the longer takes the water to seep into the cavities of asbuton material. While data of test result of permeability coefficient value to asbuton thickness without influence of water pressure with comparison between asbuton thickness with water level 1/100 is analyzed by correlation between permeability coefficient value with asbuton thickness as shown in Fig. 4.

Figure 2 shows that the thicker of the asbuton, the permeability coefficient value tends to be smaller, however all the asbuton thickness levels meet the permeability (K)<10-5 cm/sec permeability coefficient values for the core layer of the dam body.

Analysis of asbuton thickness testing due to effect of water pressure: The data of the test of permeability coefficient on water pressure at 2 cm thick asbuton

Table 7: Coef of permeability with asbuton thickness due to the effect of water pressure

Description/Units	Asbuton thickness (cm)		
	2	4	6
Water pressure (kg/cm^2)	0.8	3.2	7.2
Water level (cm)	40	80	120
Coef. Permeability (cm/sec)	8.52 E-06	8.15 E-06	7.58 E-06

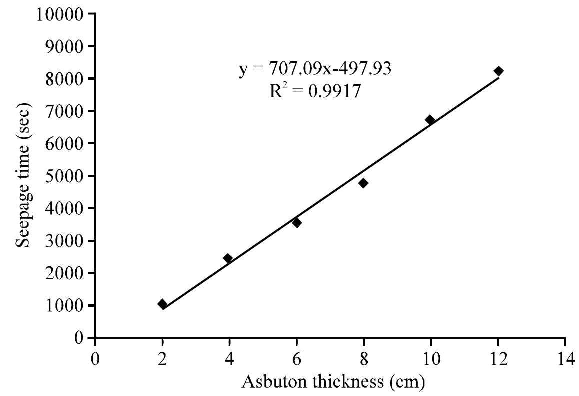

Fig. 3: Relation of time of seepage with asbuton thickness

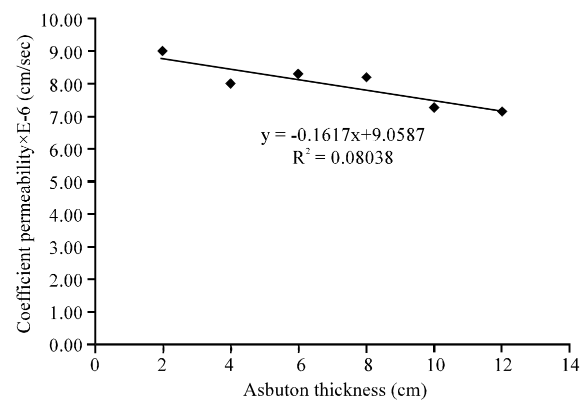

Fig. 4: Relation of coefficient of permeability with asbuton thickness without water pressure effect

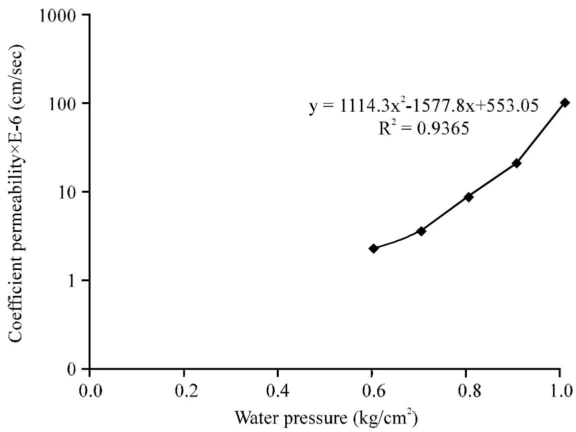

Fig. 5: Relation of coefficient of permeability with water pressure on 2 cm asbuton thickness

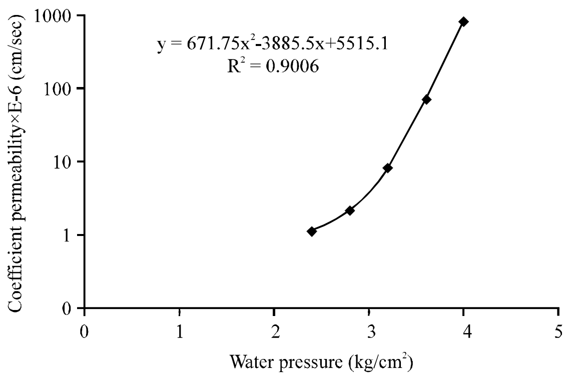

Fig. 6: Relation of coefficient of permeability with water pressure on 4 cm asbuton thickness

will be analyzed by connecting the permeability coefficient value with water pressure as shown in Fig. 5.

The data of the test of permeability coefficient on water pressure at 4 cm thick asbuton will be analyzed by connecting the permeability coefficient value with water pressure as shown in Fig. 6.

The data of the test of permeability coefficient on water pressure at 6 cm thick asbuton will be analyzed by connecting the permeability coefficient value with water pressure as shown in Fig. 7.

Figure 5 shows that at the water pressure of 1.0 and 0.9 kg/cm', the permeability coefficient value is still >10' cm/sec, then at 0.8 kg/cm' water pressure the asbuton material meets the permeability coefficient value is 8.52×10. cm/sec <10' cm/sec. At a thickness of 2.0 cm asbuton with a water pressure value of 0.8 kg/cm', then based on the coulomb equation obtained a water level 40 cm. So, the ratio between the thickness of the asbuton material and the water level is 1:20.

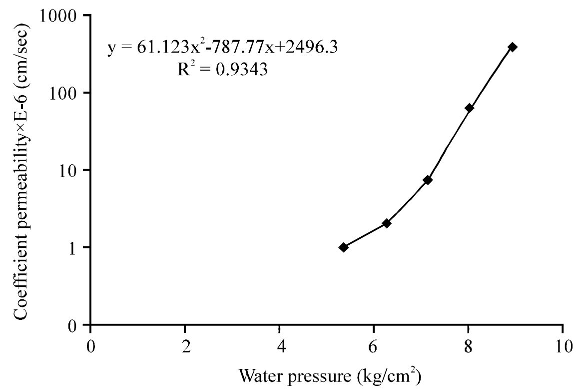

Fig. 7: Relation of coefficient of permeability with water pressure on 6 cm asbuton thickness

Figure 6 shows that at the water pressure of 4.0 and 3.6 kg/cm', the permeability coefficient value is still >10' cm/sec, then at 3.2 kg/cm' water pressure the asbuton material meets the permeability coefficient value is 8.15×10. cm/sec <10' cm/sec. At a thickness of 4.0 cm asbuton with a water pressure value of 3.2 kg/cm', then based on the Coulomb equation obtained a water level 80 cm. So, the ratio between the thickness of the asbuton material and the water level is 1: 20.

Figure 7 shows that at the water pressure of 9.0 and 8.1 kg/cm', the permeability coefficient value is still >10' cm/sec, then at 7.2 kg/cm' water pressure the asbuton material meets the permeability coefficient value is 7.58×10-6<10' cm/sec. At a thickness of 6.0 cm asbuton with a water pressure value of 7.2 kg/cm', then based on the Coulomb equation obtained a water level 120 cm. So, the ratio between the thickness of the asbuton material and the water level is 1:20.

Base on 3 eksperiments above, shows the thickness of the base layer of the core layer using asbuton material is 1/20 of the water level of the dam. While data of test result of permeability coefficient value to asbuton thickness due to influence of water pressure with comparison between asbuton thickness with water level 1/20 is analyzed by connecting between permeability coefficient value with asbuton thickness as shown in Fig. 8.

Figure 6 shows that the thicker of the asbuton material, the smaller the permeability coefficient of the asbuton material. However, all the thickness of the asbuton material satisfies the requirements of the permeability coefficient value. This shows that the ratio between the thickness of the asbuton material and the water level of the dam due to the influence of water pressure is 1:20 satisfies the permeability coefficient (K) <10' cm/sec for the core layer of the dam body.

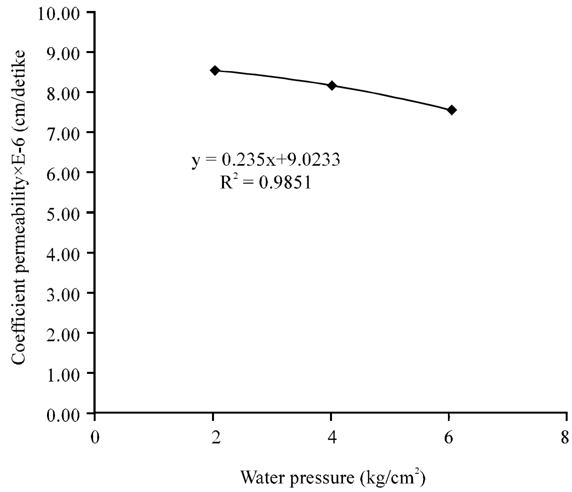

Fig. 8: Relation of coefficient of permeability with asbuton thickness due to effect of water pressure

Design model thickness core layer using asbuton: Based on the result of thickness testing of the core layer without the influence of water pressure and thickness testing of the core layer due to the influence of water pressure on the asbuton, the thickness design model of the core layer using asbuton on the dam is on the upper surface layer 1/100 of the dam water level while the base layer of the core layer is 1/20 of the dam water level. So that, the core layer construction design model using asbuton material is shown in Fig. 9 and 10.

Description:

- Thickness of core layer construction without influence water pressure
- Thickness of core layer construction due to influence water pressure
- The core layer construction model that uses asbuton material

Permeability coefficients in parts of the core layer that use asbuton material: To ensure the core layer design model with asbuton material in this study fulfills the requirements of the permeability coefficient value, then in each part of the core layer construction, the permeability coefficient is checked, that is: at 1/3 of the height of the core layer, 1/2 of the height core layer and 2/3 of the height of the core layer.

Checking the permeability coefficient on the parts of the core layer is carried out on 6 cm asbuton thickness and 120 cm high. Results checking the permeability coefficient values in parts of the core layer construction is presented in Table 7.

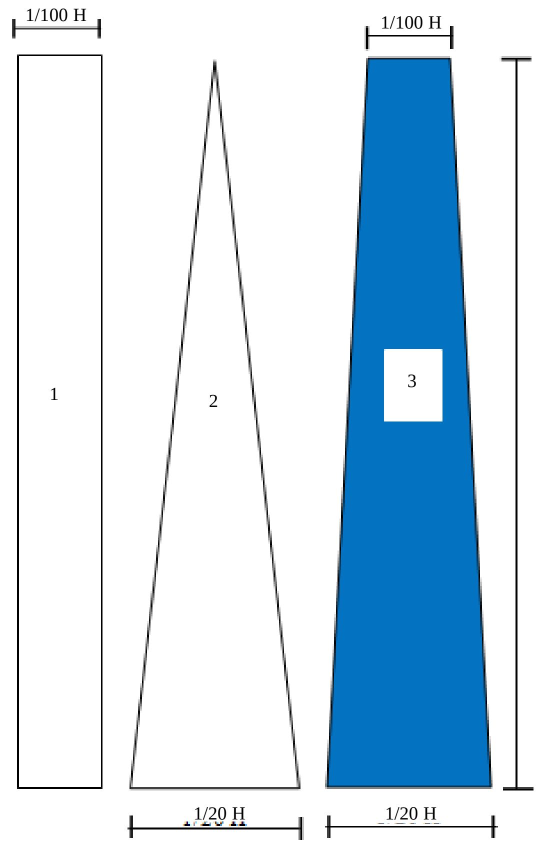

Fig. 9: Core layer construction design model using asbuton material

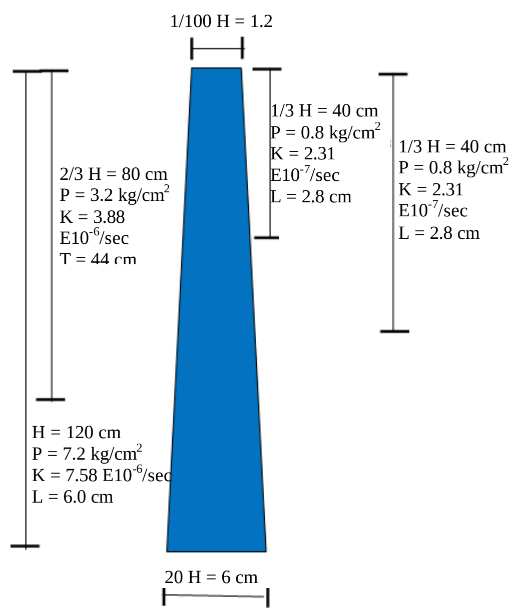

Fig. 10: Permeability coefficients on the parts of the core layer using asbuton materials

Table 8: Permeability value in the parts of the core layer using asbuton material

Descriptions/Units	High core layer (cm) H = 120	2/3 H = 80	1/2 H = 60	1/3 H = 40
Thick part of the layer (cm)	6.0	4.4	3.6	2.8
Water pressure (kg/cm^2)	7.2	3.2	1.8	0.8
Coef. permeability (cm/sec)	7.58 E-06	3.88 E-06	8.35 E-07	2.31 E-07

Table 8 shows that all parts of the core layer using asbuton material meet the requirements of the permeability coefficient (K) <10-5 cm/sec.

CONCLUSION

Based on the results of research and data analysis, it is concluded as follows: the ratio between the thickness of the asbuton and the water level of the dam at permeability testing without the influence of water pressure that satisfies the permeability value (K)<10^{-} cm/sec is 1:100. The comparison between the thickness of the asbuton and the water level of the dam on the permeability test due to the influence of water pressure that meets the permeability value (K) <10^{-} cm/sec is 1:20. The thickness design model of the core layer that uses asbuton on the dam body is on the upper surface layer 1/100 of the water level of the dam while in the base layer the core layer is 1/20 of the dam water level.

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