SEEPAGE ANALYSIS IN WULUKUT DAM, KABUPATEN KUNINGAN, WEST JAVA

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ABSTRACT

Seepage analysis in Wulukut Dam of Kuningan Town, West Java has been done. Design scenario was carried out by using numerical simulation in designing the dam of various types, to analyze the amount of seepage and the occurrence of piping and uplift pressure. Results of various simulation show that the amount of seepage ranges from 721,5 l/day/meter to 1282 l/day/meter, piping safety factor from 5 to 9 and uplift pressure safety factor from 2,22 - 2,56. The most effective of the dams is shown by type 2 ($K_{alluvial}$ = 1,00 x 10^{-3} cm/sec, earthfill dam with core and filter). The differences in hydraulic conductivity of alluvial deposit determine the seepage value, safety factors for piping and uplift, so that more exact knowledge on hydrogeological condition in the research area is very essential.

Keywords: *Wulukut dam, dam seepage analysis, safety factors.*

INTRODUCTION

Earthfill dams are hydraulic structures functioning to store and retain water. Soil used in dam body has to be of such strength, enough to prevent water flow because although dam surface is showing that water has been retained, condition in dam body and under dam structure are showing a water movement process known as seepage. This seepage is moving slowly entering through soil pores.

Water can be very destructive and may cause dam breaching. It is therefore very important to conduct an analysis on seepage as a preventive action before construction in order to decide on most appropriate soil type to be used as fill. When seepage is not controlled it may not only cause loss of property but also loss of human life. Implementation of proper control preventing such condition is thus very essential.

Wulukut Dam was constructed to fulfil the demand of raw water at Kecamatan Nusa Herang, Kabupaten Kuningan, to be used as drinking water, domestic water, and water requirement for agriculture and cattle breeding. According to design, at normal condition, water level of 10 m in the Wulukut Dam will be equal to a water volume of 52.614 m^3 sufficient to be used by the local people residing in vicinity of the Wulukut Dam.

The initial scenario design is substantial in dam construction to analyze conditions such as piping and uplift pressure[1], and is commonly performed by a numerical simulation. In order to keep the problem within context, this study was limited to the behaviour of seepage at dam structure and the permeable layer, and its relation with piping and uplift pressure at each numeric simulation.

This study shall specify the effectiveness of water seepage control and the estimation of water seepage occurrence at dam structure.

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BASIC THEORY

Calculation of water seepage uses Darcy's Law (Q, L^3/t):

$$Q = KIA \tag{1}$$

where:

K = hydraulic conductivity (L/t)

I = hydraulic gradient

A = area of flow cross-section (L^2).

Analysis on water seepage to indicate the dam safety to piping is shown by the safety factor (FK_{piping}) in the equation[2]:

$$FK_{piping} = \frac{I_{cr}}{I_n}; \quad I_{cr} = \frac{G_s - 1}{1+e} \tag{2}$$

where:

I_{cr} = critical hydraulic gradient

I_n = exit hydraulic gradient

G_s = specific gravity

e = void ratio

FK_{piping} min. = 4.

Whereas, seepage analysis for FK_{uplift} is expressed by the equation:

$$FK_{uplift} = \frac{W}{U} = \frac{L_{ABCD} \cdot \gamma_{sat} \cdot h}{L_{ADE} \cdot \gamma_w} \tag{3}$$

where :

W = Down force

U = Uplift

L_{ABCD} = ABCD area

γ_{sat} = Saturated Unit Weight

h = head

L_{ADE} = ADE area

γ_w = unit weight of water

FK_{uplift} min. = 2.50.

Water Seepage Model by PC-SEEP

PC-SEEP is used in the analysis on water seepage based on finite elements. This program shall calculate the water seepage parameters such as distribution of pore water pressure, uplift, flow velocity, flow direction, hydraulic gradient and flow volume of certain section at boundary condition.

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IMPLEMENTATION OF STUDY

The Wulukut Dam is situated at Kabupaten Kuningan (Figure 1). Some hypotheses in this study are that uncontrolled seepage and uplift pressure can cause piping at toe of the dam structure, and that seepage will still occur at each dam structure, especially earthfill dams constructed on permeable volcanic deposit.

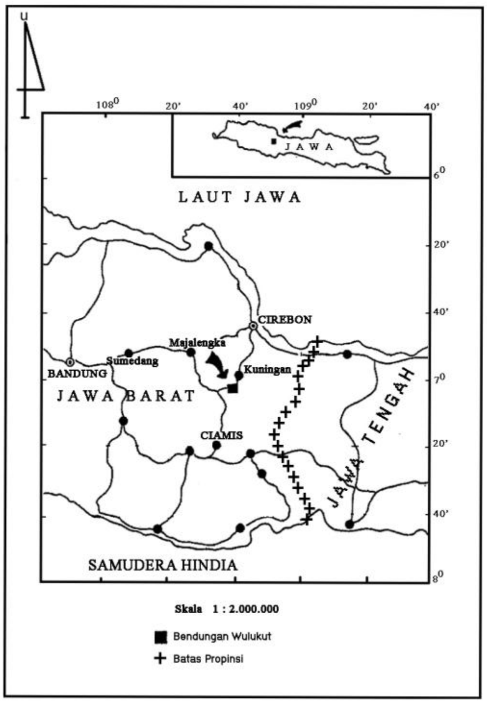

Figure 1: Location Map of Study Area

Study flowchart used in the analysis on water seepage is illustrated on Figure 2 below:

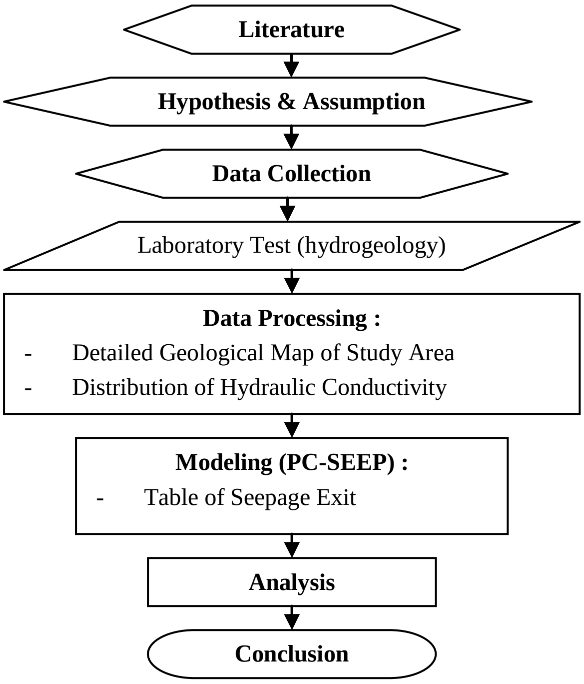

Figure 2: Flowchart of Study Method

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Primary data are collected from laboratory tests comprising hydraulic conductivity (K), specific gravity and void ratio taken at three (3) field test pit (SU. 1, SU. 2 and SU. 3). Secondary data comprised the bore logs of four (4) field core drillings, description of test pit soil properties conducted by Puslitbang Sumber Daya Air, and geological maps issued by P3G.

The scenario design was analyzed by application of the computer program PC-SEEP developed by Desai and Kuppusumy[3] and used by Puslitbang Sumber Daya Air, Ministry of Public Works illustrating two different types of dam; homogeneous earthfill dam for specification of flow distribution in dams completely made of soil and homogeneous earthfill dams complemented with dam core and filter. The filter is used to prevent particles from being transported by water flow. Scenario design is made according to two hydraulic conductivity values of a specific layer for the two aforesaid types.

GEOLOGICAL CONDITION OF STUDY AREA

Area adjacent to the proposed Wulukut Dam is surrounded by hills of +700 m to +996 m above sea level generally densely covered by pine trees, whereas open areas are cultivated as farmland by the local people (2d crop, banana, and paddy).

The Wulukut Dam is designed for construction in the Wulukut River, a tributary of the Cisanggarung River. The Wulukut River shall according to design have a width of 4m. Field measurements showed that discharge of the Wulukut River in the wet season can be 100 L/sec., and in the dry season 1.5 L/sec.

Stratigraphy

The Wulukut Dam area, Kuningan, is shown on the Tasikmalaya geological map sheet as depicted on Figure 3.

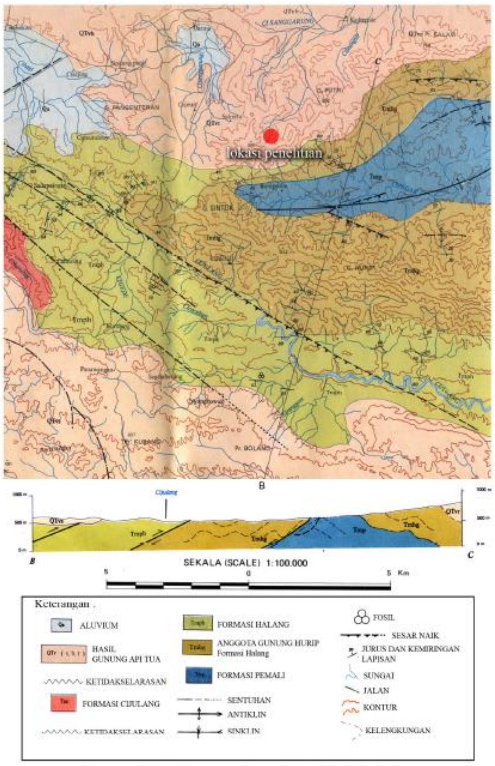

Figure 3: Tasikmalaya Geological Map Sheet

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A detailed geological map of the dam location is shown on Figure 4.

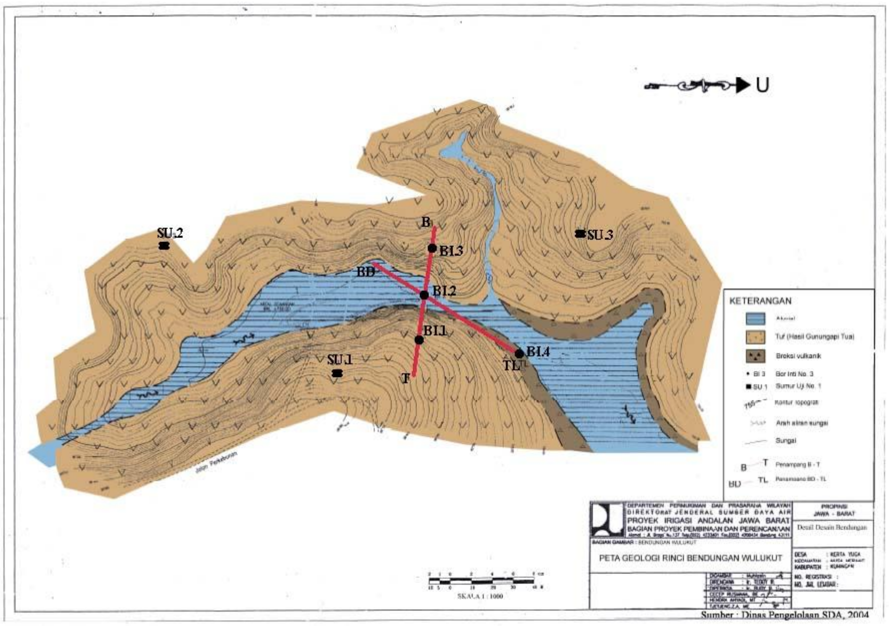

Figure 4: Detailed Geological Map of the Wulukut Dam [5]

Stratigraphical conditions of the study area are depicted on Table 1.

Table 1: Stratigraphical Conditions in vicinity of the Wulukut Dam

AGE	VICINITY OF WULUKUT DAM	LITOLOGY
Holocene	ALLUVIAL	Clay, sand, gravel and pebbles
--------------------------	Non-conformity	------------------
Plistocene Mid - End	OLD VOLCANIC MATERIAL (MT. CEREME)	Tuff, lahar breccia II, lahar breccia I, and volcanic breccias

Hydrogeology

Before dam construction, influent water increased groundwater discharge in the area of the proposed Wulukut Dam (influent, Freeze and Cherry)[1], and with the dam construction groundwater flow shall even increase more.

Soil samples were taken from some points in the vicinity of the proposed Wulukut Dam (Figure 4), and laboratory test results as material data included the specific gravity and void ratio as well as hydraulic conductivity (see Table 2).

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Table 2: Soil Mechanics Data of Proposed Wulukut Dam

LOCATION		WULUKUT DAM		
SAMPLE NO.		SU. 1	SU. 2	SU. 3
DEPTH (m)		0,20 – 3,00	0,20 – 2,50	0,20 – 2,40
SPECIFIC GRAVITY (ASTM D-854)	G_S	2,6611	2,6582	2,6531
VOID RATIO (ASTM D-2937)	e	1,088	1,137	1,171
SATURATED UNIT WEIGHT (ASTM D-2937)	γ_{sat} (gm/cm^3)	1,548	1,541	1,549
PERMEABILITY FALLING HEAD (SNI 19 - 6473 – 2000)	K (cm/sec)	$5{,}80 \times 10^{-5}$	$5{,}45 \times 10^{-8}$	$3{,}54 \times 10^{-6}$

After data had been collected, a cross-sectional hydraulic conductivity is made as basis of the seepage analysis model (Figure 5). Laboratory test data indicated K_{fill} (6) = 1.79×10^{-6} cm/sec. Field K data are used as under dam parameters with $K_{volcanic\ breccia}$(1) = 1.30×10^{-4} cm/sec, $K_{volcanic\ breccia}$ (2) = 6.00×10^{-4} cm/sec, $K_{volcanic\ breccia}$(3) = 1.70×10^{-4} cm/sec, $K_{volcanic\ breccia}$ (4) = 2.00×10^{-4} cm/sec, $K_{volcanic\ breccia}$ (7) = 5.19×10^{-4} cm/sec and $K_{lahar\ breccia\ II}$ (8) = 2.65×10^{-4} cm/sec and $K_{lahar\ breccia\ II}$ (9) = 4.10×10^{-4} cm/sec. Literature was used to determine the value of $K_{alluvial}$[1] (5) = 1.00×10^{-2} cm/sec or 1.00×10^{-3} cm/sec and K_{core}[2] (10) = 1.00×10^{-7} cm/sec.

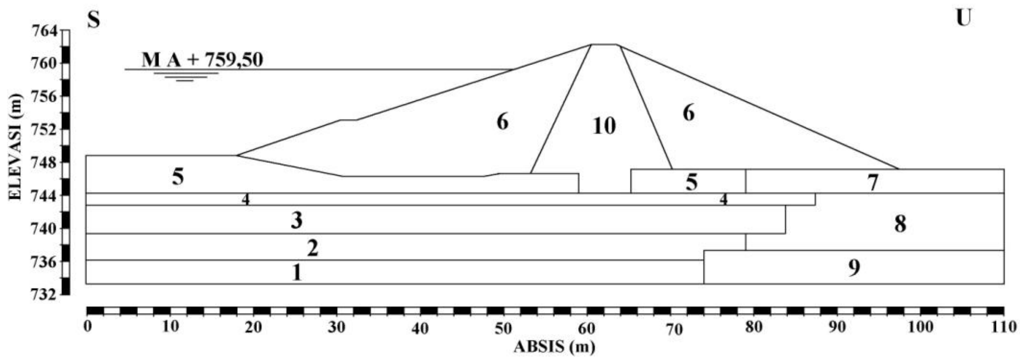

Figure 5: Hydraulic Conductivity Cross-section of the Wulukut Dam

RESULTS AND DISCUSSION

The Wulukut Dam model was made for two dam types, respectively with two different conductivity values (Table 3).

Table 3: Model of Wulukut Dam

Dam Type / $K_{alluvial}$(cm/sec)	1 Homogeneous Earthfill Dam	2 Earthfill Dam complemented with core and filter
10^{-2}	Model 1	Model 2
10^{-3}	Model 3	Model 4

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Dam model results for model 1, 2, 3 and 4 are illustrated in Figures 6, 7, 8 and 9.

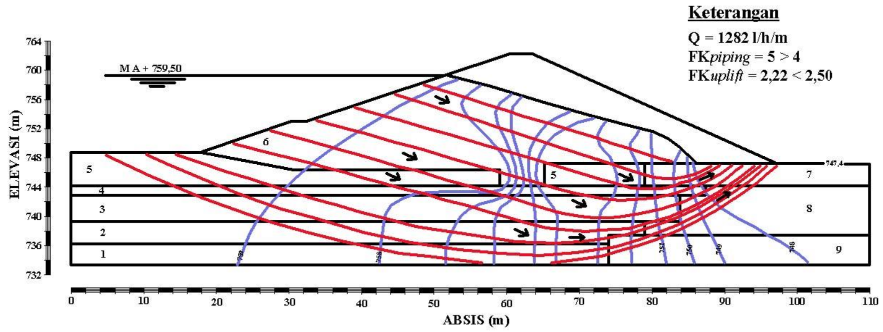

Figure 6: Results of the seepage analysis by finite element method for Wulukut Dam model 1, type 1: homogeneous earthfill dam. Red lines indicating the water flow, while the blue lines the equipotential.

Seepage calculation results for model 1 show a seepage rate of 1282 L/day/m with FK_{piping} = 5 and FK_{uplift} = 2.22. Figure 6 shows that if seepage occurs, water flow from upstream will emerge from inner downstream dam toe.

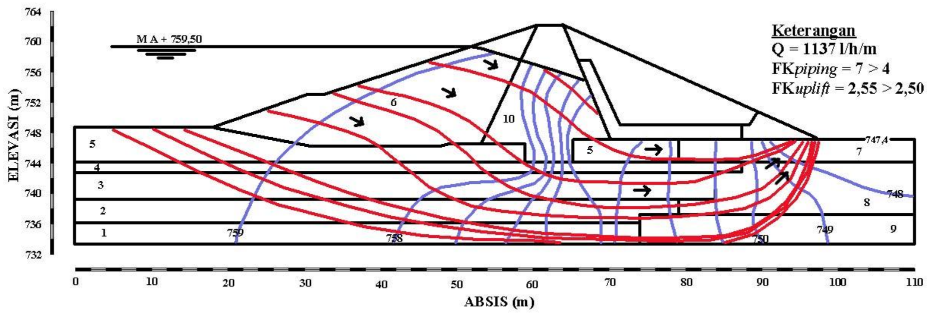

Figure 7: Results of the seepage analysis by finite element method for Wulukut Dam model 2, type 2: fill dam complemented with core and filter

Seepage calculation results for model 2 show a seepage rate of 1137 L/day/m with FK_{piping} = 7 and FK_{uplift} = 2.55. Compared to model 1, seepage had decreased with 11.3%, whereas FK_{piping} and FK_{uplift} had increased. Figure 7 shows a water flow passing the core and under the dam to emerge through the filter.

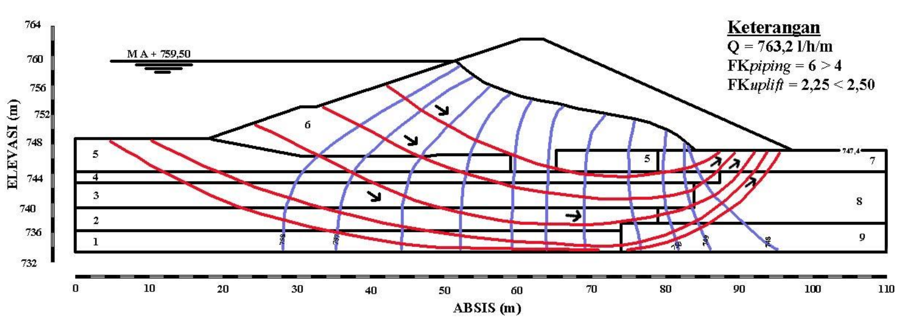

Figure 8: Results of the seepage analysis by finite element method for Wulukut Dam model 3, type 3: homogeneous earthfill dam

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Seepage calculation results for model 3 show a seepage rate of 763.2 L/day/m with FK_{piping} = 6 and FK_{uplift} = 2.25. The $K_{alluvial}$ difference of 0.1 times greater than the impermeability of model 1 decreases seepage with 40.5%. FK_{piping} and FK_{uplift} are also higher. Model of water flow and equipotential of the homogeneous earthfill dam is shown in Figure 8.

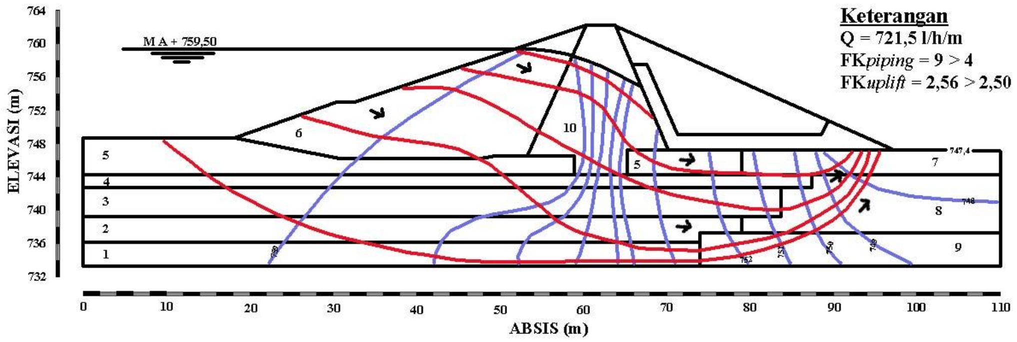

Figure 9: Results of the seepage analysis by finite element method for Wulukut Dam model 4, type 2: fill dam complemented with core and filter

Seepage calculation results for model 4 show a seepage rate of 721.5 L/day/m with FK_{piping} = 9 and FK_{uplift} = 2.56. Seepage at model 4 is 5.46% smaller compared to model 3, showing also an increase of the safety factor. If compared with model 2, seepage at model 4 had decreased with 36.5%, whereas FK_{piping} and FK_{uplift} had increased from 7 and 2.55. Figure 9 shows the application of a core and filter. Water flow passing the core and under the dam shall emerge through the filter.

Complete calculation results of two conditions of seepage can be examined on Table 5.

Table 5: Final results of seepage calculation of two types of Wulukut Dam

Type		$K_{aluvial}$ (cm/sec)	10^{-2}		10^{-3}	
1	Homogeneous	Seepage (l/day/m)	Model 1	1282	Model 3	763,2
		Fk_{piping}		5		6
		Fk_{uplift}		2,22		2,25
2	Complemented with core and filter	Seepage (l/day/m)	Model 2	1137	Model 4	721,5
		Fk_{piping}		7		9
		Fk_{uplift}		2,55		2,56

If piping and uplift are not controlled, dam structure may collapse due to stability interference, as explained by Sherard et al.[6] and Cedergren[7],

Dam models 1 and 3 can be applied unless core and drainage are increased so that uplift decreases at pressure concentration points. Uplift is controlled by flowing water through the filter so that water pressure in the void between rock particles is reduced and soil particles are not carried away. Application of core in dam structure is essential in seepage control because this zone is more impervious than the surrounding area.

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The design of the Wulukut Dam has applied a flow net to illustrate the water flow and equipotential. Homogeneous rock layers under the dam structure up to impervious surface layers shall cause irregular equipotential lines which likewise shall cause the accumulation of pressure at particular points of all models that is specified as uplift.

In general, dam effectiveness is shown by dam type 2 followed by type 1.

CONCLUSION

Study results show that the most ineffective Wulukut Dam design is indicated by model 1, with homogeneous earthfill dam type and $K_{alluvial}$ = 1.00 x 10^{-2} cm/sec. This condition is shown by the seepage rate of 1282 L/day/m, FK_{piping} = 5 and Fk_{uplift} = 2.22. Whereas, the most effective design is indicated by model 4, with earthfill dam complemented with core and filter and $K_{alluvial}$ condition = 1.00 x 10^{-3} cm/sec as explained by seepage rate of 721.5 L/day/m, FK_{piping} = 9 and Fk_{uplift} = 2.56. Differences in the hydraulic conductivity of alluvial deposit may influence the seepage rate and safety factor to piping and uplift. Therefore, more accurate specification of hydro-geological conditions in study area is substantial.

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