The Effect Of Groundsill Height On Bridge Pillar Flow Characteristics

(Physical Model)

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ABSTRACT

Groundsill is one of the categories of wide thresholds that are generally built transversely in the river downstream of a building threatened with damage caused by scouring such as bridge pillars. In addition to construction factors, local scour around the pillars can be another factor causing the collapse of the bridge structure. The purpose of this study was to determine the effect of groundsill height on flow characteristics. Physical model research on open channels (flume) was carried out at the Integrated Laboratory of Sultan Ageng Tirtayasa University, Sindangsari Campus. The groundsill model is modeled with dimensions of 8 cm peak width, 30 cm length, and groundsill height variations (1, 2, 3, 4, and 5 cm) made of wood while the bridge pillar model is modeled with a diameter of 1 inch made of PVC pipe which is filled with concrete. The results showed that the higher the groundsill (p), the higher the water level upstream (H_1) is greater and downstream (H_2) is smaller, while the flow speed upstream (V_1) is smaller and downstream (V_2) is greater so that the Froude number downstream is greater than upstream. The higher the groundsill (p), the Froude number downstream will increase (supercritical flow) while upstream will decrease (subcritical flow).

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1. INTRODUCTION

Rivers are natural water reservoirs that separate one region from other areas and function to drain the flow of water. Areas separated by rivers can be connected using bridges that serve to provide access to people or vehicles between two areas separated by rivers [1]. On some bridges there are pillars and abutments as a bridge load supporter [2]. The construction of pillars and abutments can cause changes in flow characteristics such as changes in flow speed and turbulent flow, resulting in changes in the river bed and resulting in local scouring around the pillars.

Various pillar shapes have been developed to minimize basic scour but have not yet given maximum results [3]. Local scour around the pillars can be one of the factors causing the collapse of the bridge structure [4] as well as the liquidation due to vibration from vehicles crossing the bridge construction [5]. The scouring process occurs naturally as part of river morphology due to river buildings blocking one of the bridge pillar buildings [6].

One approach that can be used to optimally minimize local scour problems is to think of methods of reducing river flow speed, namely by building pillar safety buildings such as groundsill buildings. Groundsills are generally built downstream of a river building that is threatened with damage caused by local scouring such as on bridge pillars [7] which aims to reduce the speed of current and increase the rate of sediment deposition in the upstream part of the groundsill [8]. Sediment carried by water currents due to local scouring on bridge pillars can be restrained by groundsill so that the basic material around the pillars does not experience excessive decline [9].

Groundsills are built not to dam the flow or raise the water table, in contrast to the weir [10] which has the main function of raising the water level to obtain the desired waterfall height to flow into irrigation canals [11]. *Groundsill* is one of the buildings built to stabilize the riverbed so that it remains stable and not damaged [12], so it is one form of effort to control the riverbed so that there is no excessive subsidence. The excessive subsidence of the river bed is caused by the erosion of sediment supply from upstream river structures such as dams, sabo dams, and others [13].

Groundsill is expected to reduce scouring problems that occur in the riverbed so that it can protect existing buildings in the river flow [14], but groundsills can also have a negative impact, one of which is reduced sediment supply from upstream and degradation of the riverbed downstream of the groundsill so that in the dry season when the water elevation is very low, the existence of *groundsill* is considered less environmentally friendly [15].

The purpose of this study was to determine the effect of groundsill height on flow characteristics. This physical model research is located in the Integrated Laboratory of Sultan Ageng Tirtayasa Sindangsari University, Pabuaran District, Serang Regency, Banten Province. Previous research related to this study, namely Pradana & Khumairah, (2021) conducted research on the influence of flow characteristics on scouring that occurs around pillars. Tajriana & Jumarrni, (2020) conducted research on changes in scour patterns that occur before and after the presence of concrete wing curtains on bridge pillars. Putra et al., (2018) conducted research on flow patterns in the absence of pillars with pillars. Purwantoro, (2015) conducted a study on the effect of groundsill installation and abutment wing shape on scouring that occurs around bridge abutments. Fajar Riani, (2018) conducted research on the influence of groundsill and abutment on sediment flow form. Based on previous research, no research has been conducted on the effect of groundsill height on flow characteristics, so the limitation of the problem in this study is not discussing scouring and sedimentation and not scaling the model.

2. METHODS

This physical model research was conducted using open channels (flume) at the Integrated Laboratory of Sultan Ageng Tirtayasa University, Sindangsari Campus.

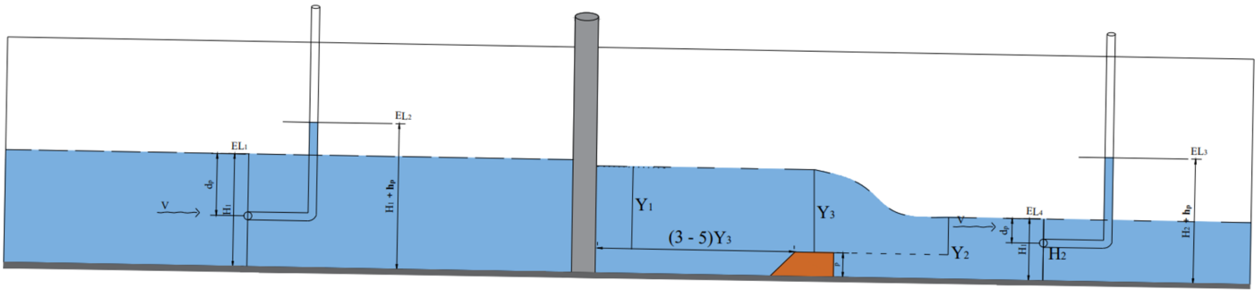

Figure 1. Model Sketch and Pitot Tube Speed Gauge

The steps of this research are as follows:

1. Study of previous research literature and literature
2. Problem statement
3. Groundsill and pillar modeling
4. Non-dimensional analysis
5. Calibrate the pitot tube measuring instrument
6. Model operation
7. Analysis of research results

2.1 Tools and Materials

The tools and materialsused to support this research are as follows:

1. Open channel (flume) with a width of 30 cm, a height of 46.5 cm, and a length of 5 m.
2. Pitot tube measuring instrument.

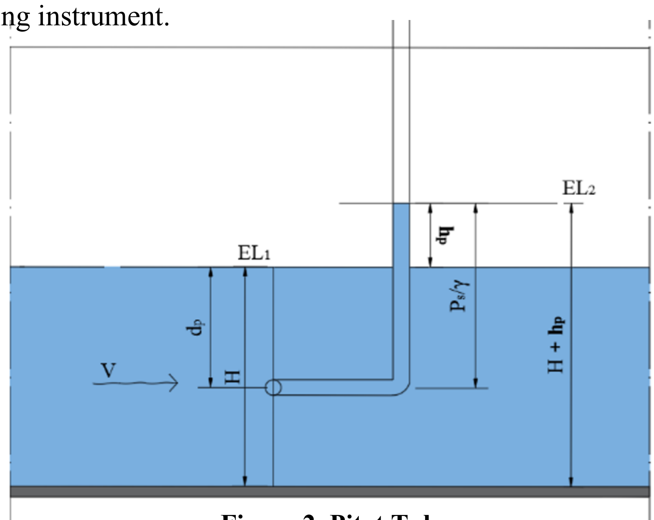

Figure 2. Pitot Tube

3. The groundsill model is modeled with dimensions of 8 cm peak width, 30 cm length, and groundsill height variations (1, 2, 3, 4, and 5 cm) made of wood.
4. The pillar model with a diameter of 1 inch is made of PVC material pipe inside which is filled with concrete.

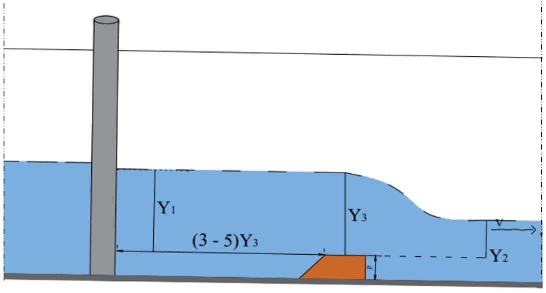

Figure 3. Groundsill and Pillar Models

5. *Point gauge.*

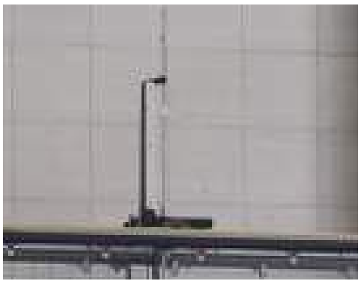

Figure 4. ***Point Gauge***

6. Roll meter.

2.2 Reserach Model

This research uses physical models by modeling groundsill and pillar. The width threshold model (groundsill) is modeled with dimensions of 8 cm groundsill peak width, 30 cm length, and groundsill height variations (1, 2, 3, 4, and 5 cm) made of wood. While the pillar are modeled with 1" diameter PVC pipes filled with concrete.

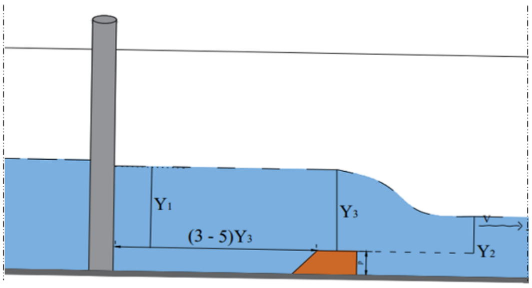

Figure 5. Groundsill and Pillar Models

2.3 Variables

The variables studied in this study are the slope of the bottom of the channel (i), the height of the water table upstream (H_1), the height of the water table downstream (H_2), the height of the groundsill (p), the width of the groundsill (b), the flow discharge (Q), the flow speed (V), and the Froude number (Fr).

2.4 Calibration of Pitot Tube

Calibration of the pitot tube measuring instrument needs to be done to obtain a speed equation that matches the condition of the pitot tube measuring instrument at the time the measurement is made. The calibration measurement of the pitot tube measuring instrument is carried out with five variations of discharge, the amount of which is regulated through the rotation of the pump on the electric console. Speed measurement is carried out by the three-point depth method, namely 0.2H, 0.6H, and 0.8H. The pitot speed coefficient (C_p) is obtained using the equation:

$$C_p = \frac{V\ Actual}{V\ Theoretical} \qquad (1)$$

The actual or corrected flow speed is determined through the 'calibration of the pitot tube and manometer' graph.

2.1 Non Dimensional Analysis

Non-dimensional analysis is carried out using basic stepwise methods. Based on the physical variables that affect the flow at the imperfect width threshold: $f(p, Y_1, Y_2, H_1, g, V)$, a non-dimensional analysis is obtained with the following relationship:

$$\left(\frac{p}{H_1}, \frac{Y_1}{H_1}, \frac{Y_2}{H_1}\right) = \frac{V}{\sqrt{gH_1}}$$

3. RESULTS AND DISCUSSION

The calibration of the pitot tube speed measuring instrument greatly affects the accuracy of measurements in this study. The effect of groundsill height on bridge pillars flow characteristics can be known through measurements based on the variables studied. The measurement results are then compared to variables that are very influential in the dimensionless model depicted through non-dimensional analysis graphs.

3.1 Calibrating Pitot Tube Analysis

Calibration of the pitot tube measuring instrument needs to be done to obtain a speed equation that matches the condition of the pitot tube measuring instrument at the time the measurement is made. The data required for the calibration of the pitot tube measuring instrument are the height of the water table (H), the depth of the pitot tube from the water surface (d_p), the elevation of the water table in the pitot tube from the datum (EL_2), the high pressure that occurs ($\frac{Ps}{\gamma}$), the height of the water table occurring in the pitot tube (h_p), the flow speed determined through the graph 'calibration of the pitot tube and manometer' ($V_{Corrected}$) and the flow speed through measurement using a pitot tube measuring instrument ($V_{Measured}$).

Tabel 1. Pitot Tube Calibration Measurement Data

No	Round Pump	H (m)	$\frac{Ps}{\gamma}$ (mm)	$V_{Corrected}$ (m/det)	$V_{Measured}$ (m/det)	C_p
1	4,45	0,0792	69,94	0,5850	0,7193	0,8133
2	4,20	0,0735	66,05	0,5500	0,7085	0,7763
3	3,95	0,0655	60,40	0,5350	0,6902	0,7752
4	3,70	0,0615	55,53	0,5000	0,6513	0,7677
5	3,45	0,0549	49,67	0,4800	0,6180	0,7768
			C_p Average			**0,7818**

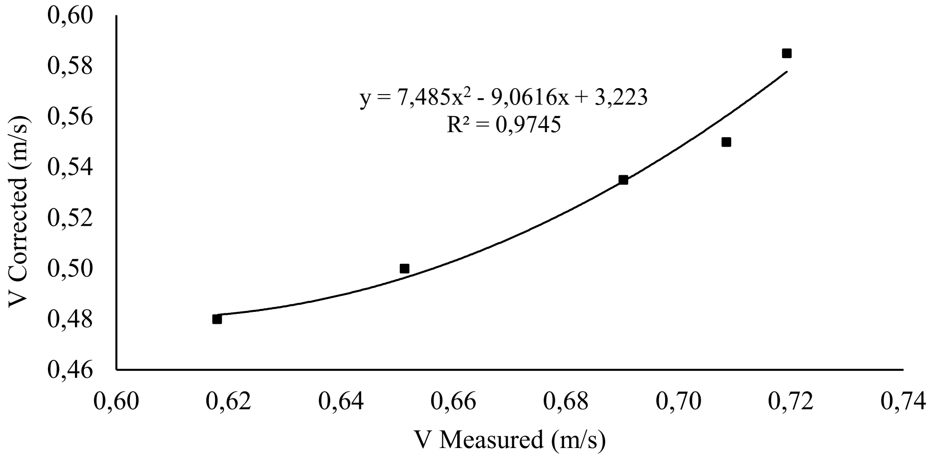

Figure 6. Relationship of $V_{Corrected}$ and $V_{Measured}$

Based on Table 3, obtained the value of the pitot speed coefficient (C_p) = 0,7818. Based on Figure 6, the relationship between $V_{Corrected}$ and $V_{Measured}$ obtained the equation $y = -7,485x^2 – 9,0616x + 3,223$ and the value of $R^2 = 0,9745$.

3.2 The Effect of Groundsil Height on Bridge Pillar Flow Characteristics

Data collection of pillar flow characteristics with groundsill whose height is varied at the time of research in the laboratory is depicted in a sketch as in the following figure:

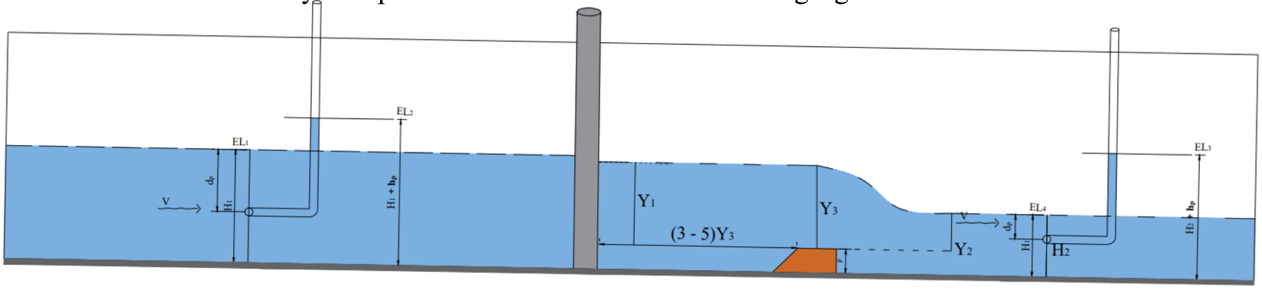

Figure 7. Sketch of Groundsill Flow Characteristics on Pillars with Groundsill Height Variations

The measured data are groundsill height (p), water level upstream (H_1) channel, water level downstream (H_2) channel, flow speed upstream (V_1) channel, flow speed downstream (V_2) channel with pitot tube, depth of pitot tube from water surface (d_p), elevation of water table height in pitot tube from datum upstream (EL_2), the elevation of the water table in the pitot tube from the datum downstream (EL_3), and the height of the water table that occurs in the pitot tube (h_p). The results of measuring water level elevation and flow speed in models with groundsill height variations, channel bottom slope of 0,5% and fixed discharge are shown in Table 2.

Table 2. Groundsill Measurement Data on Pillars with Groundsill Height Variation

No	p (m)	Upstream			Downstream		
		H_1 (m)	d_p (m)	h_p (m)	H_2 (m)	d_p (m)	h_p (m)
1	0,05	0,1495	0,0897	0,0195	0,0535	0,0321	0,1100
2	0,04	0,1410	0,0846	0,0230	0,0545	0,0327	0,1045
3	0,03	0,1300	0,0780	0,2950	0,0575	0,0345	0,1000
4	0,02	0,1220	0,0732	0,0340	0,0650	0,0390	0,0890

No	p (m)	Upstream			Downstream		
		H_1 (m)	d_p (m)	h_p (m)	H_2 (m)	d_p (m)	h_p (m)
5	0,01	0,1195	0,0717	0,0350	0,0695	0,0417	0,0810

Data Table 2. analyzed to obtain the flow speed and Froude number. The results are shown in Table 3.

Table 3. Characteristics of Groundsill Flow on Pillars with Groundsill Height Variations

No	p (m)	Upstream Channel			Downstream Channel		
		H_1 (m)	V_1 (m/det)	Fr	H_2 (m)	V_2 (m/det)	Fr
1	0,05	0,1495	0,4836	0,3993	0,0535	1,1485	1,5854
2	0,04	0,1410	0,5252	0,4465	0,0545	1,1194	1,5310
3	0,03	0,1300	0,5948	0,5267	0,0575	1,0951	1,4581
4	0,02	0,1220	0,6385	0,5837	0,0650	1,0331	1,2937
5	0,01	0,1195	0,6479	0,5984	0,0695	0,9856	1,1936

Based on Table 3, it is known that the flow characteristics in the groundsill on the pillar that the water level in the upper reaches of the channel (H_1) is greater than the water level downstream (H_2) of the channel, while the flow speed downstream of the channel (V_2) is greater than the flow speed in the upper reaches of the channel (V_1) as well as the value of the Froude number (directly proportional to the flow speed upstream and downstream). The higher the groundsill (p), the water level in the upper reaches of the channel (H_1) will be greater, while the water level downstream of the channel (H_2) will be smaller. The flow speed upstream (V_1) is getting smaller and the flow speed downstream (V_2) of the channel will be getting bigger. The Froude number of flows upstream of the channel is getting smaller, while the Froude number of flows downstream of the channel is getting bigger (directly proportional to the flow speed upstream and downstream). Flow types downstream of the groundsill include supercritical flow ($Fr > 1$), while flow types upstream of the groundsill include subcritical flow ($Fr < 1$).

3.3 Non Dimensional Analysis

Based on the results of tests that have been carried out, it is known that the height of the groundsill greatly affects the flow speed that occurs upstream of the channel, the higher the groundsill, the value of the flow froude in the upstream channel will be smaller. The results of non-dimensional analysis obtained relationships $(\frac{p}{H_1},\frac{Y_1}{H_1},\frac{Y_2}{H_1}) = \frac{V}{\sqrt{gH_1}}$. The following is the result of calculating the effect of groundsill height (p) with water level in the upper reaches of the channel (H_1) on the Froude value in the upper reaches of the channel that has been calculated:

Table 4. p/H₁ and Froude Number at Upstream Channel

No	p (m)	H_1 (m)	p/H_1	Fr Upstream
1	0,05	0,1495	0,3344	0,3993
2	0,04	0,1410	0,2837	0,4465
3	0,03	0,1300	0,2308	0,5267
4	0,02	0,1220	0,1639	0,5837
5	0,01	0,1195	0,0837	0,5984

The effect of groundsill height (p) with water level in the upper reaches of the channel (H_1) on the Froude value in the upper reaches of the channel obtained the relationship as in the following graph:

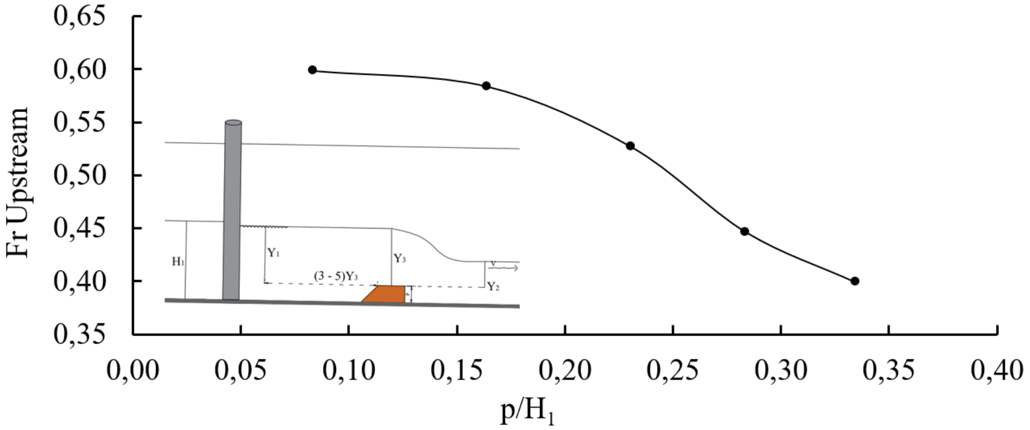

Figure 6. The relationship of p/H_1 and Fr Upstream Groundsill on Pillar with Groundsill Height Variations

It is known that the smaller the value of the comparison of the groundsill height (p) with the water level in the upper reaches of the channel (H_1), the value of the flow Froude number in the upper reaches of the channel will be greater, where the smaller the comparison value, the groundsill height (p) and the water level in the upper reaches of the channel (H_1) obtained are smaller.

The following is the result of calculating the effect of the water level upstream of the groundsill from the groundsill landmark (Y_1) with the water level in the upper reaches of the channel (H_1) on the Froude value in the upper reaches of the channel:

Tabel 5. Y_1/H_1 and Froude Number at Channel Upstream

No	**Y_1 (m)**	**H_1 (m)**	**Y_1/H_1**	***Fr* Upstream**
1	0,0998	0,1495	0,6676	0,3993
2	0,0985	0,1410	0,6986	0,4465
3	0,0998	0,1300	0,7677	0,5267
4	0,0977	0,1220	0,8008	0,5837
5	0,0967	0,1195	0,8092	0,5984

The effect of the water level upstream of the groundsill from the groundsill landmark (Y_1) with the water level in the upper reaches of the channel (H_1) on the Froude value in the upper reaches of the channel obtained the relationship as shown in the following graph:

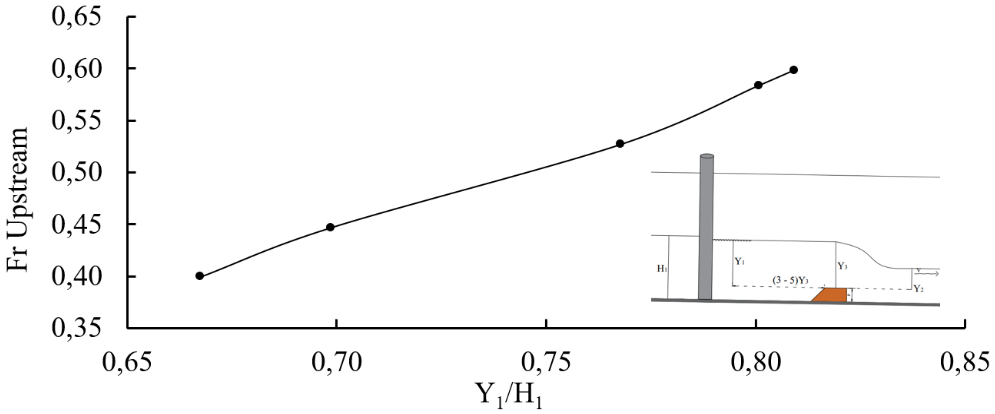

Figure 7. Relationship Y_1/H_1 and Fr Upstream Groundsill on a Pillar with Groundsill Height Variation

It is known that the smaller the value of the comparison of the water level upstream of the groundsill of the groundsill peak (Y_1) with the water level in the upper reaches of the channel (H_1), the value of the flow Froude number in the upper reaches of the channel will be smaller, where the smaller the comparison value, the water level upstream of the groundsill peak (Y_1) and the water level upstream of the channel (H_1) obtained is getting bigger and bigger. This is due to the influence of the groundsill height (p). The following is the result of calculating the effect of the water level downstream of the groundsill from the groundsill peak (Y_2) with the water level in the upper reaches of the channel (H_1) on the Froude value in the upper reaches of the channel on the Froude value in the upper reaches of the channel:

Table 6. Y_2/H_1 and Froude Number in Upstream Channel

No	Y_2 (m)	H_1 (m)	Y_2/H_1	Fr Upstream
1	0,0035	0,1495	0,0234	0,3993
2	0,0145	0,1410	0,1028	0,4465
3	0,0275	0,1300	0,2115	0,5267
4	0,0450	0,1220	0,3689	0,5837
5	0,0595	0,1195	0,4979	0,5984

The effect of the water level downstream of the groundsill from the groundsill landmark (Y_2) with the water level in the upper reaches of the channel (H_1) on the Froude value in the upper reaches of the channel obtained a relationship as shown in the following graph:

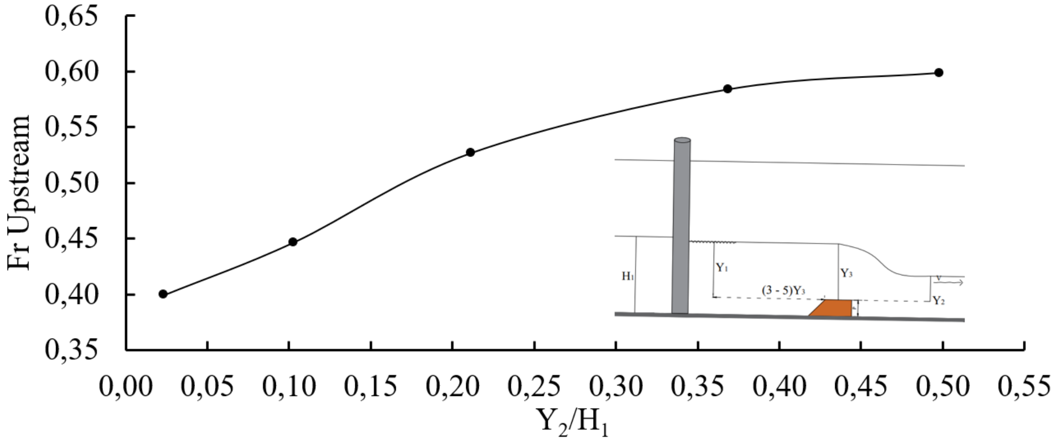

Figure 8. Relationship Y_2/H_1 and Fr Upstream Groundsill on a Pillar with Groundsill Height Variation

It is known that the smaller the value of the comparison of the height of the water table downstream of the groundsill of the groundsill landmark (Y_2) with the water level in the upper reaches of the channel (H_1), the value of the flow Froude number in the upper reaches of the channel will be smaller, where the smaller the comparison value, the water level downstream of the groundsill from the groundsill landmark (Y_2) is smaller while the water level in the upper reaches of the channel (H_1) obtained is getting bigger and bigger. This is due to the influence of the height of the groundsill (p), the higher the groundsill, the higher the water level downstream of the groundsill (Y_1) will be smaller.

4. CONCLUSION

Based on the results of research that has been carried out in the laboratory, it can be concluded that when the condition of the slope of the bottom of the channel is 0,5% and the pump rotation is 6,0, the higher the groundsill (p), the water level upstream (H_1) is getting bigger and the water level downstream (H_2) is getting smaller, while the flow speed upstream (V_1) is getting smaller and the flow speed downstream (V_2) will be greater, as well as the Froude number flow upstream and downstream (directly proportional to speed). Flow types downstream of the groundsill include supercritical flow ($Fr > 1$), while flow types upstream of the groundsill include subcritical flow ($Fr < 1$).

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