Civil Engineering and Architecture 11(3): 1107-1124, 2023 http://www.hrpub.org
DOI: 10.13189/cea.2023.110301

Analysis of Stability Safety Factors of Gabion Weir Models against the Wall and Water Level Variation

Abdul Khamid[1,2,*], Slamet Imam Wahyudi[2], Soedarsono[2]

[1]Department of Civil Engineering, Universitas Muhadi Setia Budi, Brebes, Jawa Tengah, Indonesia
[2]Postgraduate Program of Civil Engineering, Universitas Islam Sultan Agung, Semarang, Indonesia

Received August 5, 2022; Revised December 24, 2022; Accepted January 28, 2023

Cite This Paper in the Following Citation Styles

(a): *[1] Abdul Khamid, Slamet Imam Wahyudi, Soedarsono , "Analysis of Stability Safety Factors of Gabion Weir Models against the Wall and Water Level Variation," Civil Engineering and Architecture, Vol. 11, No. 3, pp. 1107 - 1124, 2023. DOI: 10.13189/cea.2023.110301.*

(b): *Abdul Khamid, Slamet Imam Wahyudi, Soedarsono (2023). Analysis of Stability Safety Factors of Gabion Weir Models against the Wall and Water Level Variation. Civil Engineering and Architecture, 11(3), 1107 - 1124. DOI: 10.13189/cea.2023.110301.*

Abstract The phenomenon of climate change that is happening in the world causes global warming, which has an impact on rising sea levels causing floods and tidal floods. Research on the Gabion weirs as an alternative to appropriate technology is the first step to address either the problem of tidal flooding mitigation or as a raw water filter. This prototype test research was carried out at the Hydraulics Laboratory of the Sultan Agung Islamic University, Semarang. It employed a quantitative method by conducting prototype testing to justify field conditions by handling close results. The research analysis technique began by collecting primary data and secondary data. The design of the Gabion weir models as a filter included three types of weir testing models, namely type 1 trapezoidal model, type 2 beam model, and type 3 combination model. The material, geometry and dimensions of the experimental prototype are a reduction of the real problem conditions in the field. The results of the observation analysis of the Gabion weirs have obtained the average elevation of the water, MAR = 10 cm, MAB 60 cm, MAN = 45 cm, the elevation of the MAB upstream of the weir =65 cm, the elevation of the center of the weir = 44.5 cm, the downstream weir MAB = 41 cm, the measured flow velocity upstream of the weir 0.75 l/s, center 0.75 l/s, downstream 0.6 l/s and upstream temperature 31°C, center 30.3°C, 30°C, clean downstream water conditions. The results of the study represent a function of the elevation of the flood water level both upstream and downstream which are through the Gabion Weirs with several thicknesses as raw water filters.

Keywords Stability Safety Factors, Gabion Weir Models, Water Level Variation

1. Introduction

1.1. Background

There has been a noticeable rise in the number of reported flooding events worldwide in recent years. In dam spillways, gabion structures provide one method of flood prevention. The computer modeler faces an additional hurdle with these kinds of structures since flow through the porous gabions needs to be simulated[1][2]. The latest global catastrophe is caused by climate change and global warming. The rise in sea level, which causes floods and tidal floods, is one of the effects of climate change that is readily apparent[3][4]. The flood discharge, water channel hydraulics, water reservoir volume, and the suitable pump capacity must all be determined through analysis[5].

Based on the above facts, one alternative to do is how to build a weir as a flood control reservoir in the rainy season and additionally can be efficiently used in the dry season[6]. The availability of the gabion weirs is expected to reduce flood disasters in coastal areas and will indirectly improve the standard of living of the local community.

In order for the weir, one of the key elements in the design planning project for the gabion weir, to be able to survive for a long time, it must be designed and constructed as much as feasible. One crucial need for ensuring the longevity of the weir and its capacity to increase the water level that flows during floods is that the weir created must comply with the stability standards. A gabion weir's permeability allows substances and aquatic life to pass through it, making it more environmentally friendly than an impermeable weir. Additionally, gabion weirs provide a low-afflux alternative design that could be used to reduce flash floods[7]. Weir stability is a phrase used to describe a weir's capacity to withstand internal and external stresses, including overturning, shifting, collapse, and external forces brought on by earthquakes. It indicates that the weir is in great working order and may be utilized as a weir.

Research on the Gabion weirs as a reasonable alternative to appropriate technology constitutes the first appropriate step to address the problem of tidal flood mitigation and as a raw water filter. For many different objectives, including diversion works, river training, soil stabilization, and water delivery schemes, gabions are used to build weirs[8]. The use of Gabion weirs in the modern era for irrigation on agricultural land during the dry season, floods, tidal-waves and filters is the first step to address the problem of controlling estuary river water to irrigate rice fields and raw water to contribute as a parameter of the planning of the Gabion weirs as a device for addressing the problem of tidal floods[9][10]. Structures like gabion weirs, which can be designed as broad crested weirs, are suitable for reducing flash floods with little harm to the aquatic ecosystem[11].

This study looks at the water elevation in four different Gabion weir model scenarios as a weir to raise the water level and filter. In testing the prototype utilizing an open circuit channel at the Sultan Agung Islamic University's hydraulics lab in Semarang, research on the proper and appropriate form of the cocktail model was typically needed. This was performed by simulating 3 types of Gabion weirs, namely by testing the filter level, elevation and safety against vertical and horizontal forces[12].

2. Literature Review

The forces acting on the Gabion weirs are the vertical force and the horizontal force required for the safety of the weir stability as follows:

(a) Vertical force due to self-weight of the Gabion Weirs

The building's own weight is determined using the structure's size and the materials it is made of. The moment, which is thought to be the weakest point, is the sum of all the force's weight times the distance to the point of view.

$$G = V \ x \ \gamma \quad (1)$$

where V=Volume (m3), Density of material, namely Split Stone or Gravel.

(b) Horizontal force which is hydrostatic force

This force is transmitted through the cross-section's center of gravity, the upstream and downstream pressures on the weir's surface. The forces acting on the vertical projection of the dam surface are the horizontal component Wh and the vertical component Wv of the hydrostatic force, and their magnitude is for each unit width.

$$H = [1/2 \ x \ \gamma_w \ x \ h^2] \quad (2)$$

γ_w =Density of water (kg/m^3) =1 t/m^3 =1000 kg/m^3, H= Hydrostatic compressive force (tons), h_1=Depth of upstream water (m), h_2=Depth of downstream water (m). Gabion weir force scheme can be seen in Figure 1.

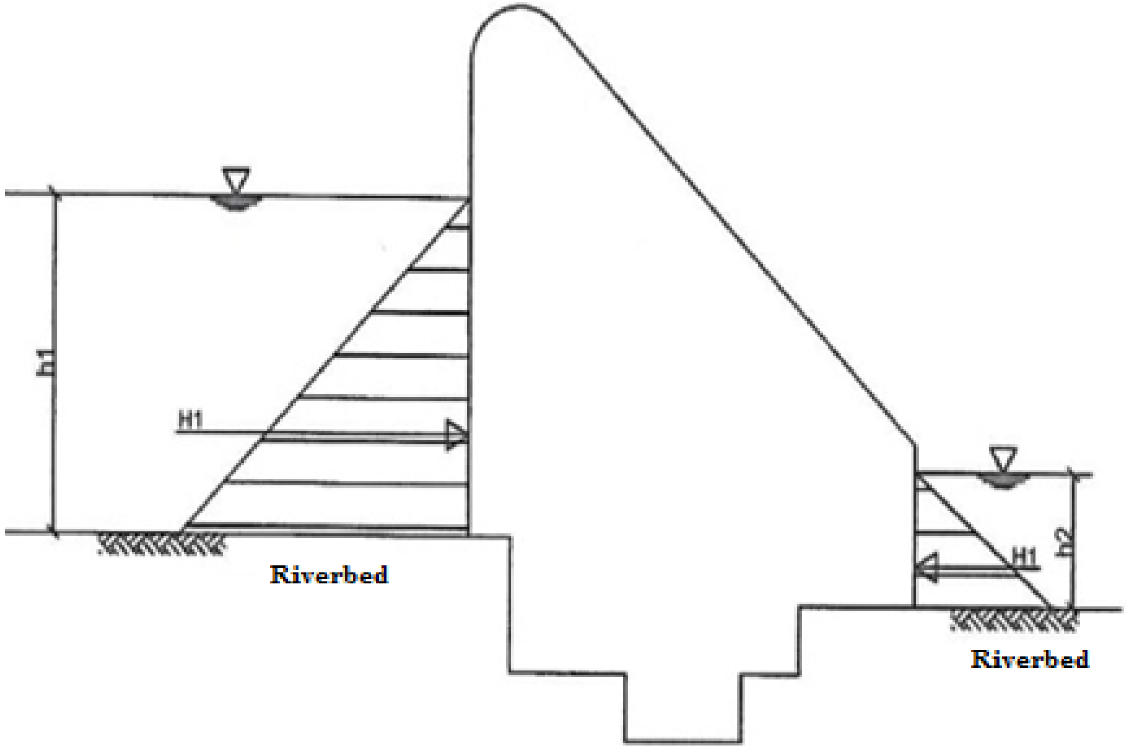

Figure 1. Plan in the style of Gabion Weir

(c) Stability Against Overturning

The weakest point is used to assess overturning stability, and from there the acting forces are computed and overturning may be approximated, while the forces that prevent overturning include both the hydrostatic force—which is directed in the opposite direction from the hydrostatic force that causes the overturning—and the weight of the building itself. Inspection of overturning must satisfy the criteria.

(d) Stability Against Overturning

The weakest point is used to assess overturning stability, and from there the acting forces are computed and overturning may be approximated, while the forces that prevent overturning include both the hydrostatic force which is directed in the opposite direction from the hydrostatic force that causes the overturning and the weight of the building itself. Inspection of overturning must satisfy the criteria.

$$SF = \frac{\sum M_t}{\sum M_g} > 1{,}2 \tag{3}$$

where SF=Factor of safety, ∑Mt Number of holding moments (ton meters), ∑Mg=Number of overturning moments (ton meters)

(e) Stability against shear

The frictional pressure of the foundation and any forces acting in the opposite direction of the force creating the shear will oppose the horizontal forces that result in shear, while the direction of the shear force is opposed to the hydrostatic force, which is the force that resists.

$$SF = \frac{\sum Pv}{\sum Ph} > 1{,}2 \tag{4}$$

where SF=Factor of safety, ∑Mg = Cumulative vertical force, ∑Ph=Cumulative horizontal force

Earthquake force

The formula used is αd = n (αcxz) m

$$E = \frac{\alpha d}{g} \tag{5}$$

Where :
αd = design earthquake acceleration (cm/dt^2)
n,m = coefficients for each type of soil
c = basic shock acceleration = 160 (cm/dt^2) for 100th return period

Ground press force.

There are two kinds of forces due to earth pressure:

1. Active Earth Pressure

$$Pa=½\ \gamma.Ka.H^2 \tag{6}$$

Passive Earth pressure

$$Pa=½\ \gamma.Kp.H^2 \tag{7}$$

3. Research Methods

This study uses a quantitative method with a weir, and the test is in the form of a prototype. The research analysis technique begins with primary data collection including field observation data and hydraulics data, while secondary data was obtained from the results of previous analysis and literature review. The research flowchart can be seen in Figure 2.

The experimental material was chosen because it was easy to obtain in the field. The geometric shapes were selected in 3 scenarios according to the guidelines for water structures in Indonesia, while the dimensions of the prototype were made based on non-dimensional analysis with a half dimension reduction of the real construction. The design of the gabion weir model as a filter is 3 types of weir testing models, namely type I Beam model, type 2 Beam with inclined upstream, type 3 Trapezoidal model and model type 4 Trapezoid and Geotextile. A gabion weir made of 4-5 cm long pieces of sandstone and 1-2 cm thick gabion wire is used as a filter. Using a flow velocity monitoring equipment, the gabion weir was tested as a filter. Utilizing a diver and a piezometer, a current meter is used to measure the water's elevation.

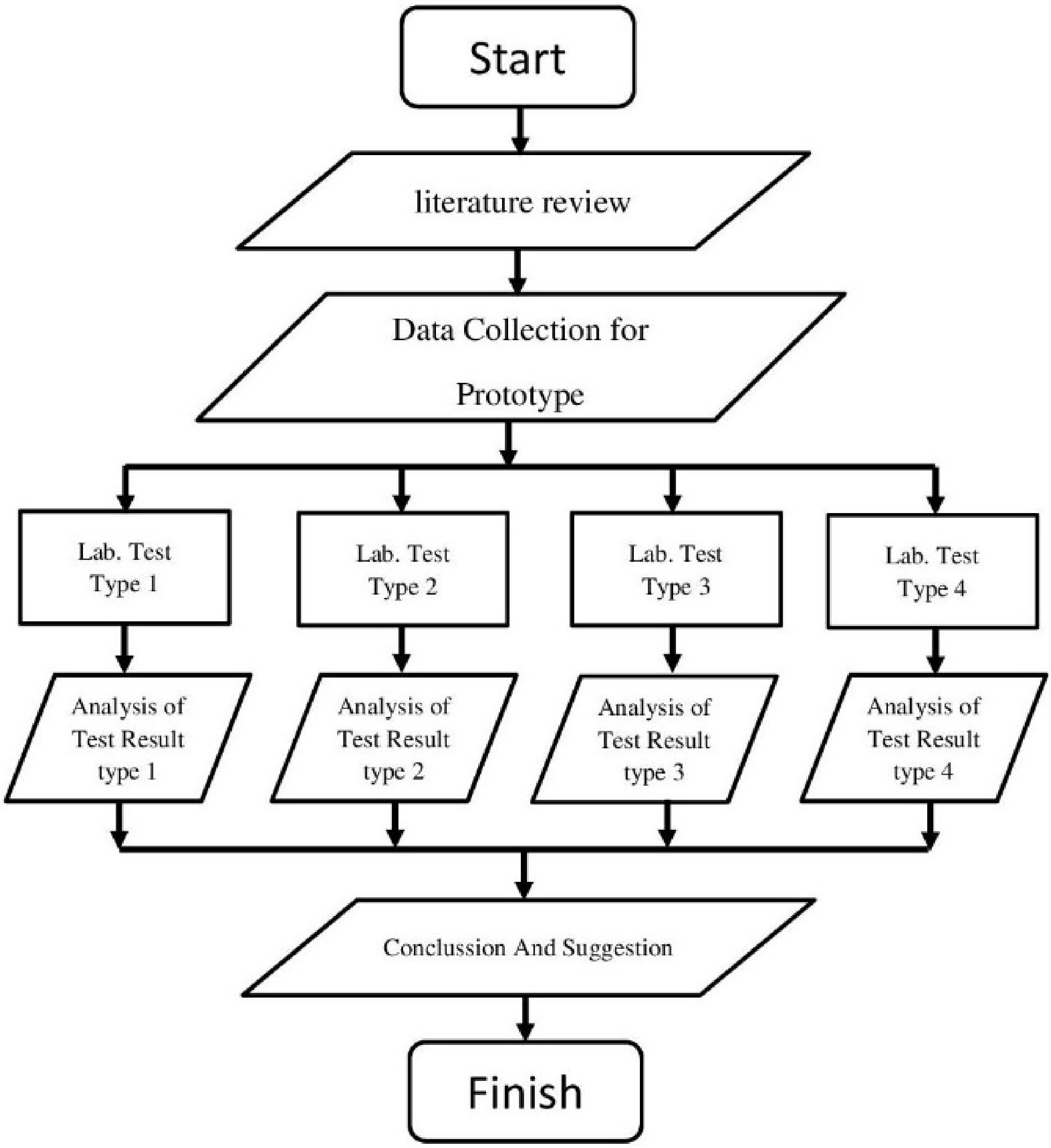

Figure 2. Research Methodology Flow Chart

4. Research Result

Gabion Weir design as a water level filter, with four test scenario models, namely type 1 Gabion Weir in the form of Beams, with gravel material, type 2 Gabion Weir in the form of inclined upstream beams with gravel, type 3 Gabion Weir in a trapezoidal shape with gravel, and type 4 Gabion Weir with trapezoidal shape with gravel + geotextile material. In testing the gabion weir as a filter, the current meter was used to adjust the elevation, while the diver and piezometer were used to monitor the elevation.

The analysis was carried out based on laboratory test observation data and hydraulic review.

Model 1: the Gabion Beam Weir Model, can be seen in Figure 3.

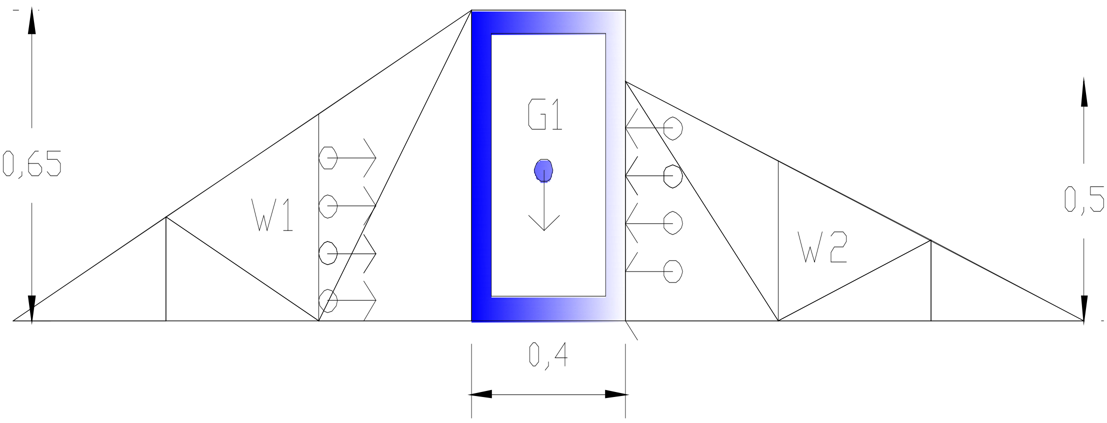

Figure 3. Model 1, Beam Gabion Weir

$$\text{Overturning stability}=\frac{\Sigma MT}{\Sigma MG}\ \text{Shear Stability}=\frac{fx\Sigma V}{\Sigma h}$$

Overturning Stability and Shear Stability Model 1 Beam Gabion Weir, can be seen in Table 1.

Table 1. Overturning Stability and Shear Stability Model 1 Beam Gabion Weir.

h (cm)	Stability against overturning	h (cm)	Stability against shearing
1	18.784	1	34.046
5	17.610	5	31.698
10	16.436	10	29.350
15	15.262	15	27.002
20	15.262	20	25.828
25	14.088	25	23.480
30	12.914	30	22.306
35	11.740	35	19.958
40	10.566	40	18.784
45	9.392	45	17.610
50	8.218	50	16.436
55	7.044	55	14.088
60	5.870	60	12.914
65	4.696	65	10.566
70	3.522	70	8.218
75	2.348	75	5.870

Output SF (Safety Factor) Manual Calculation of Reverse Stability and Shear Stability can be seen in Figure 4.

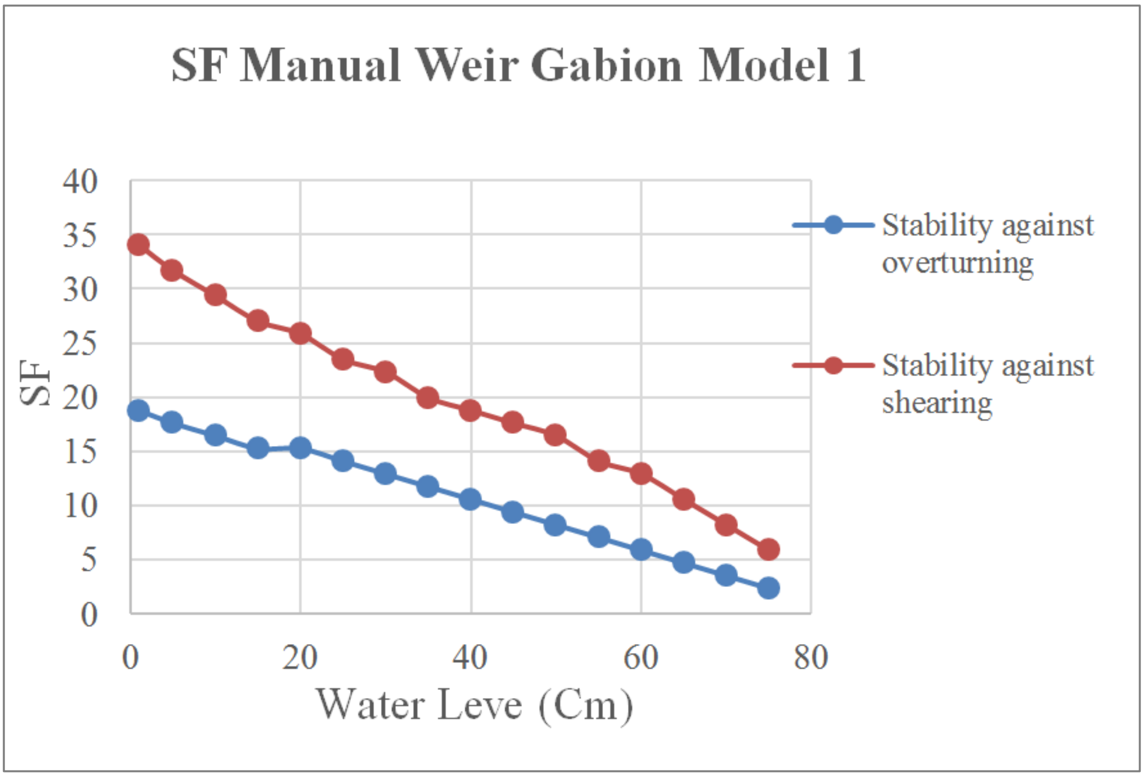

Figure 4. Graph of Output SF Manual Overturning and Shear Stability Calculations

Plaxis Software Output Total Displacement HWL can be seen in Figure 5.

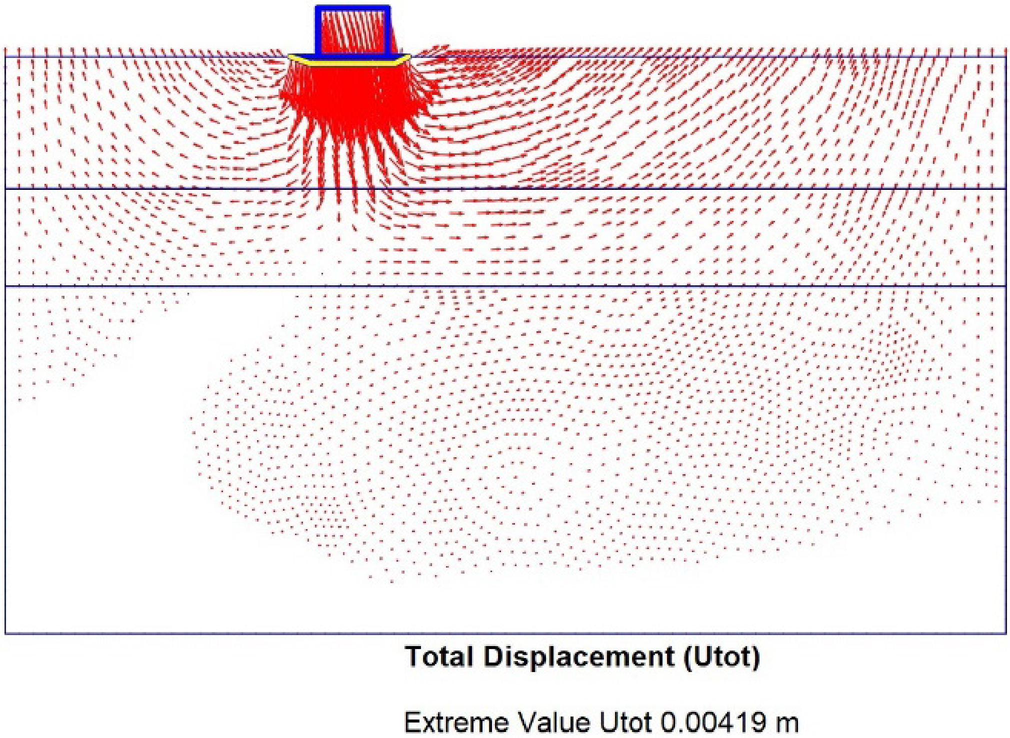

Figure 5. Plaxis Software Output Total Displacement HWL

Plaxis Software Output Average Voltage HWL, can be seen in Figure 6.

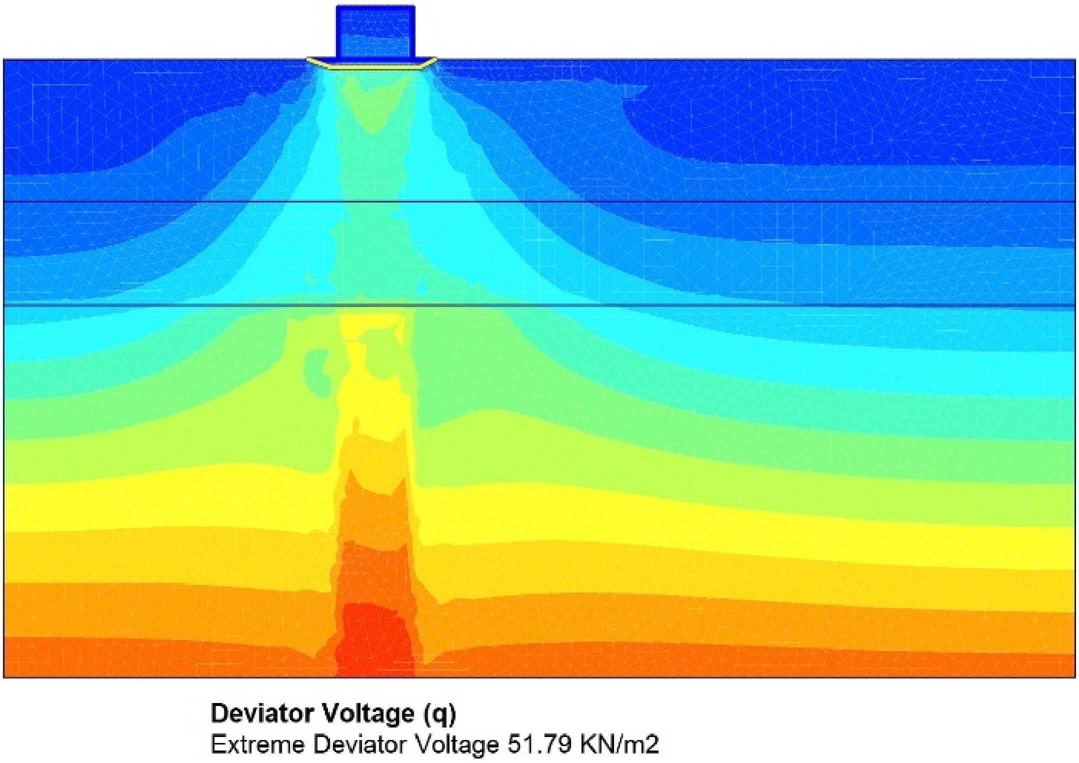

Figure 6. Average Voltage of the Plaxis Software Output HWL

Water Level Analysis for Weir Test. Water Level Elevation for Weir Gabion Model 1, can be seen in Figure 7.

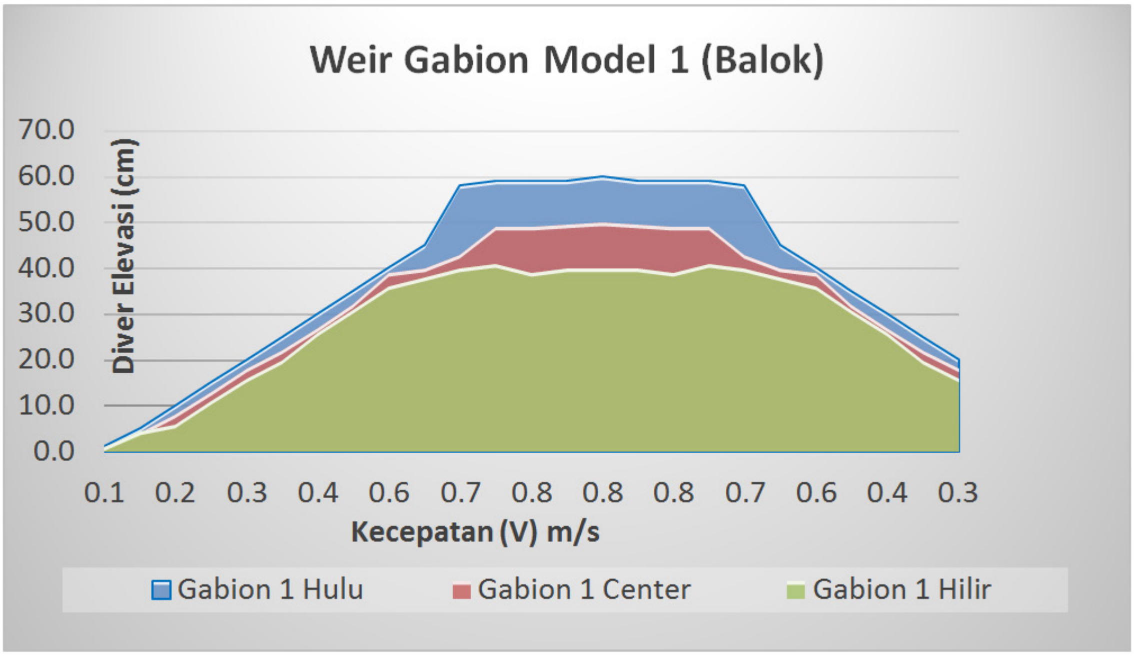

Figure 7. Water Level Elevation for Weir Gabion Model 1

1. Weir model 1 shows observations of the Diver device with the weir elevation value remaining stable. In the trial, it was found that the elevation of LWL20= cm, MWL= 40 cm and HWL = 60 cm.
2. Weir model 1 remains stable against shear and overturning forces when the water reaches High water level =60 cm.

3. Test values were determined for the upstream Gabion weir at 1.6 cm/s and 20 °C, the center at 0.9 cm/s and 15 °C, and the downstream weir at 0.6 cm/s and 14 °C using observations made using a current meter.
4. In simulation using plaxis software, the value of factor of LWL= 1.201, MWL= 1.198, HWL= 1.174 with the value of total deformation $393.94x10^{-3}$, efective stress -245,79 KN/m^2.

- Model 2: Weir Gabion Beam with Sloping Upstream can be seen in Figure 8.

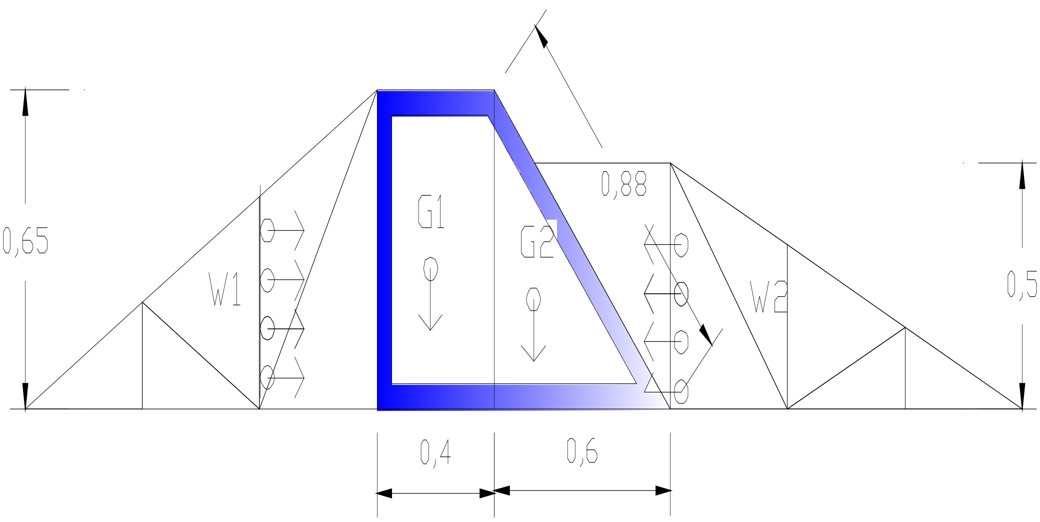

Figure 8. Model 2 Weir Gabion Beam with Sloping Upstream

$$\text{Overturning stability}=\frac{\Sigma MT}{\Sigma MG}\ \text{Shear Stability}=\frac{fx\Sigma V}{\Sigma h}$$

Overturning stability and Shear Stability Model 2

Weir Gabion Beam can be seen in Table 2.

Table 2. Overturning Stability and Shear Stability Model 2 Weir Gabion Beam

h (cm)	Stability against overturning	h (cm)	Stability against shearing
1	52.308	1	96.770
5	47.949	5	76.718
10	43.590	10	62.334
15	39.231	15	58.847
20	34.872	20	55.359
25	30.513	25	48.821
30	26.154	30	43.154
35	21.795	35	37.052
40	17.436	40	31.821
45	13.077	45	22.667
50	8.718	50	15.257
55	7.628	55	13.949
60	6.539	60	13.077
65	5.449	65	11.769
70	4.359	70	10.462
75	2.180	75	9.590

SF (Safety Factor) Output Graph for Manual Calculation of Overturning Stability and Shear Stability can be seen in Figure 9.

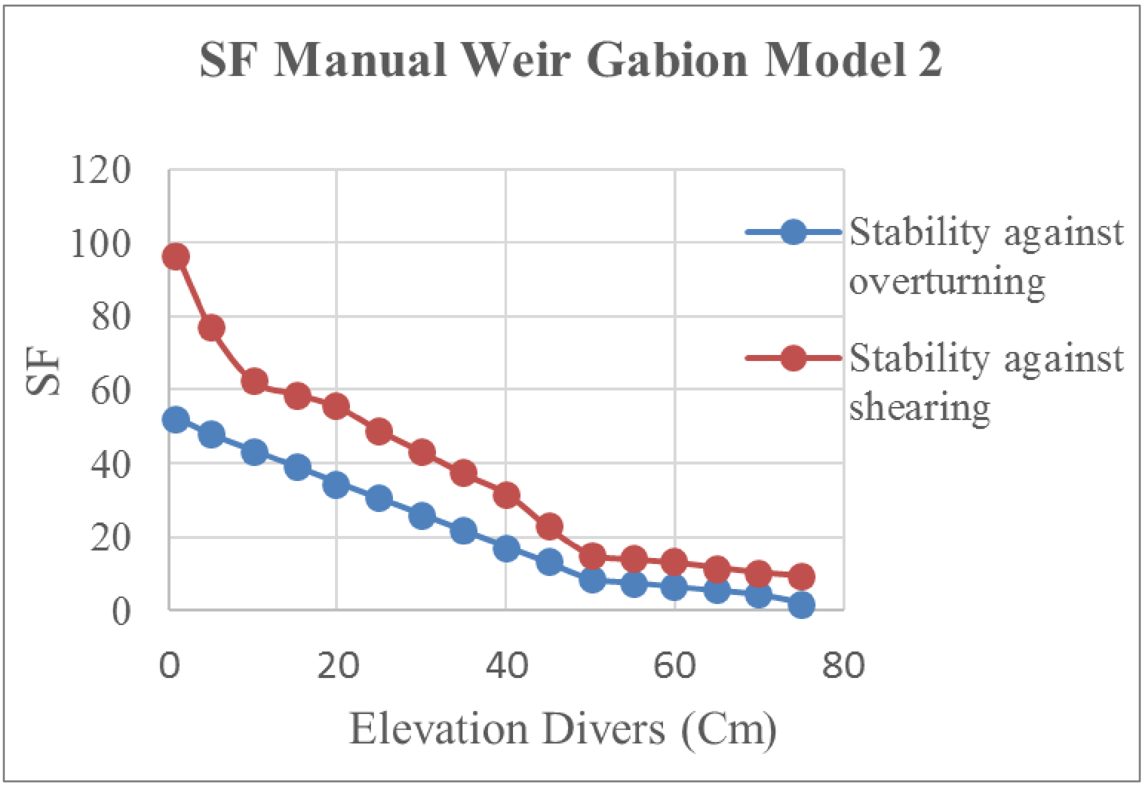

Figure 9. SF Output Graph for Manual Calculation of Overturning Stability and Shear Stability

Plaxis Software Output Total Displacement HWL (High Water Level) can be seen in Figure 10.

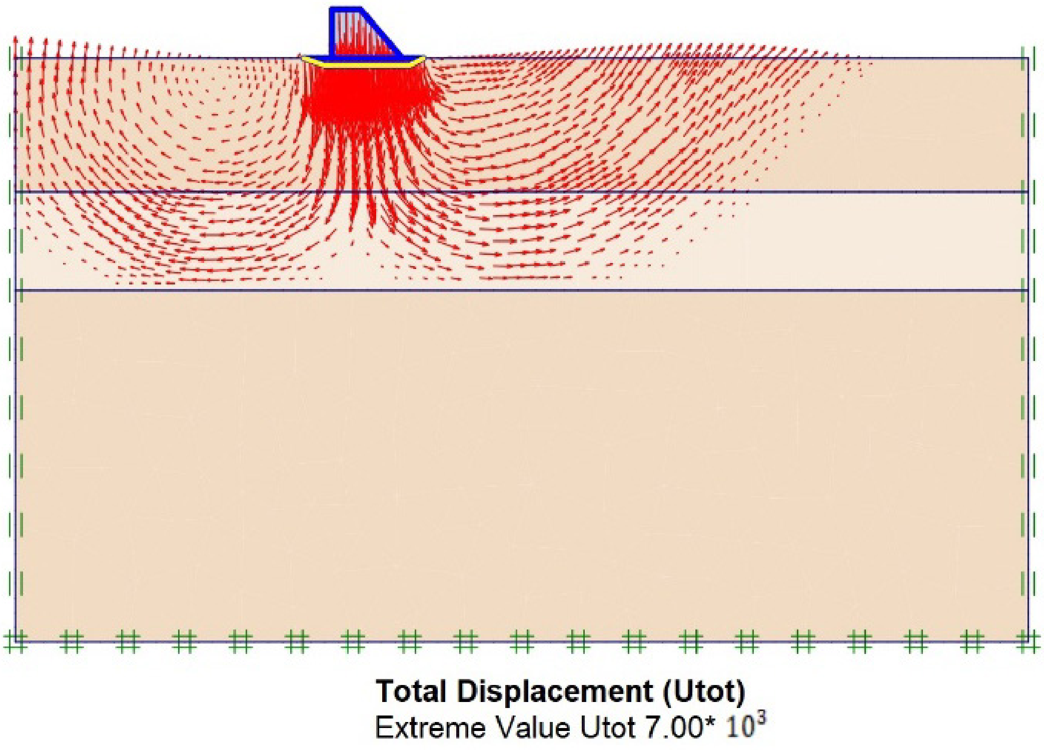

Figure 10. Plaxis Software Output Total Displacement HWL

Plaxis Software Output Average Voltage HWL can be seen in Figure 11.

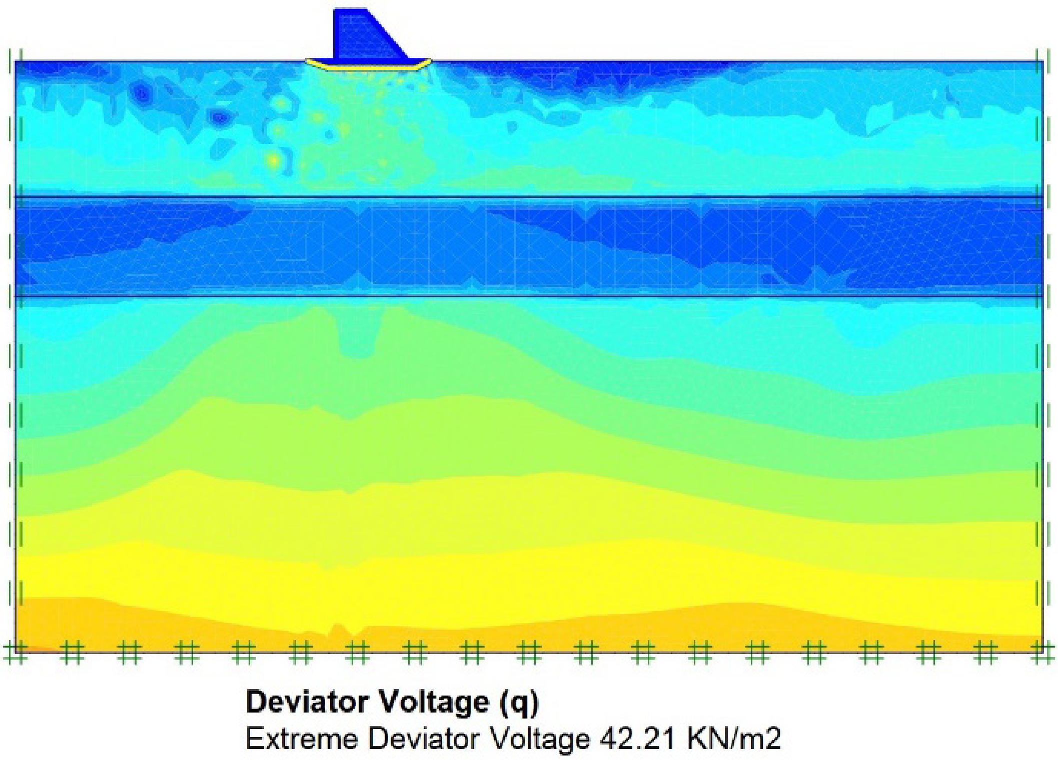

Figure 11. Average Voltage HWL of the Plaxis Software Output

Water Level Analysis for Weir Test

Elevation Water Level Weir Gabion Model 2 can be seen in Figure 12.

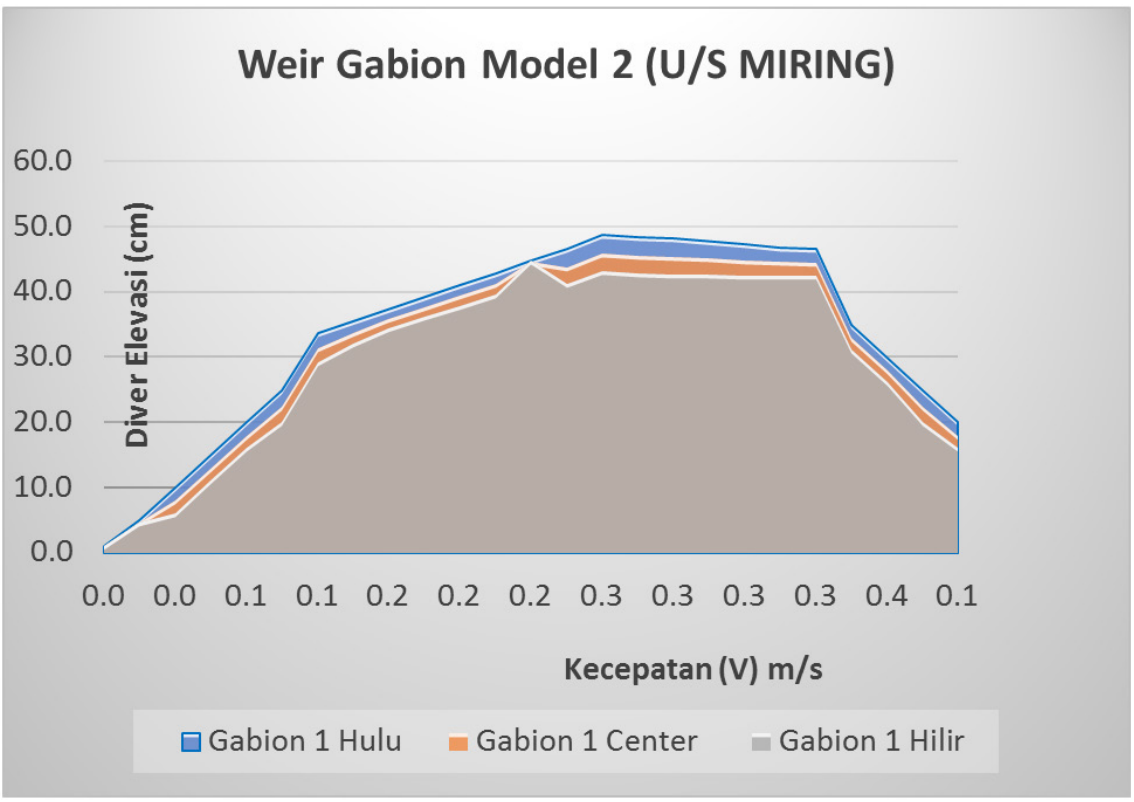

Figure 12. Elevation Water Level Weir Gabion Model 2

1. The diver device is observed using Weir Model 2, with the weir elevation value maintaining constant. It was discovered throughout the experiment that the elevation of LWL was 20 cm, MWL was 40 cm, and HWL was 60 cm.
2. Weir model 1 maintains stability against shear and overturning g forces. Height of water = 60 cm.
3. The results of observations using the Current meter device on the flow velocity and temperature of the highest water temperature found the value of the Gabion weir upstream = 1.6 cm/s and 20°C, center = 0.9 cm/s and 15°C, downstream = 0.6 cm/s and 14 °C.
4. In the simulation results using Plaxis software, it was found that the value of Safety factor LWL=4.652, MWL= 4.340, HWL = 4.359 with a total deformation value of 393.94x10^{-3}, effective stress -245,79 KN/m^2.

- Model 3 Trapezoidal Gabion Weir can be seen in Figure 13.

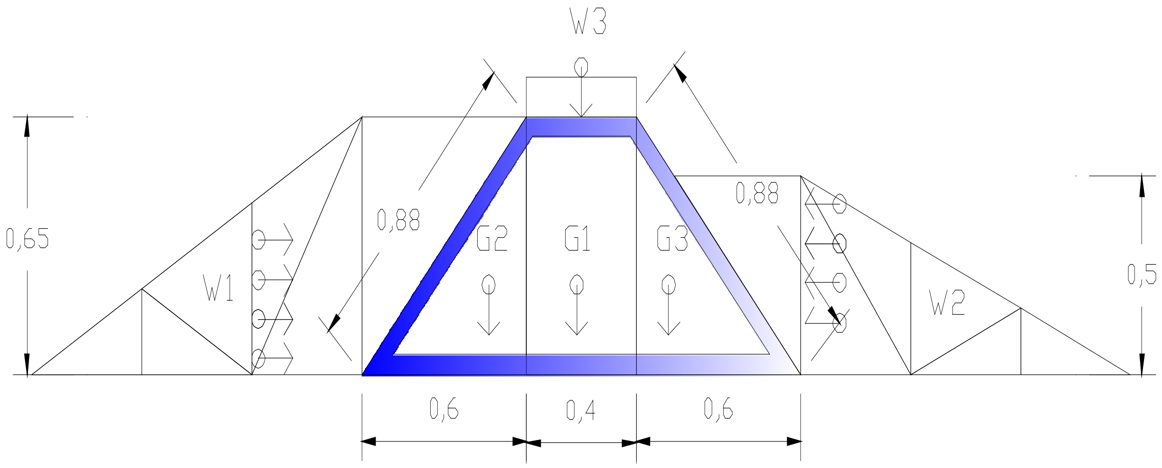

Figure 13. Model 3 Trapezoidal Gabion Weir

$$\text{Overturning stability}=\frac{\Sigma MT}{\Sigma MG}\ \text{Shear stability}=\frac{fx\Sigma V}{\Sigma h}$$

Overturning Stability and Shear Stability Model 3 Trapezoidal Gabion Weir can be seen in Table 3.

Table 3. Overturning Stability and Shear Stability Model 3 Trapezoidal Gabion Weir

h (cm)	Stability against overturning	h (cm)	Stability against shearing
1	49.533	1	81.955
5	45.030	5	59.890
10	40.527	10	50.884
15	36.024	15	41.428
20	31.521	20	36.024
25	27.018	25	31.071
30	22.515	30	28.819
35	18.012	35	27.018
40	13.509	40	24.767
45	9.006	45	22.065
50	5.404	50	20.714
55	4.953	55	17.562
60	4.503	60	14.860
65	4.053	65	9.907
70	3.602	70	6.755
75	3.152	75	4.503

SF Output Graph for Manual Calculation of Overturning Stability and Shear Stability can be seen in Figure 14.

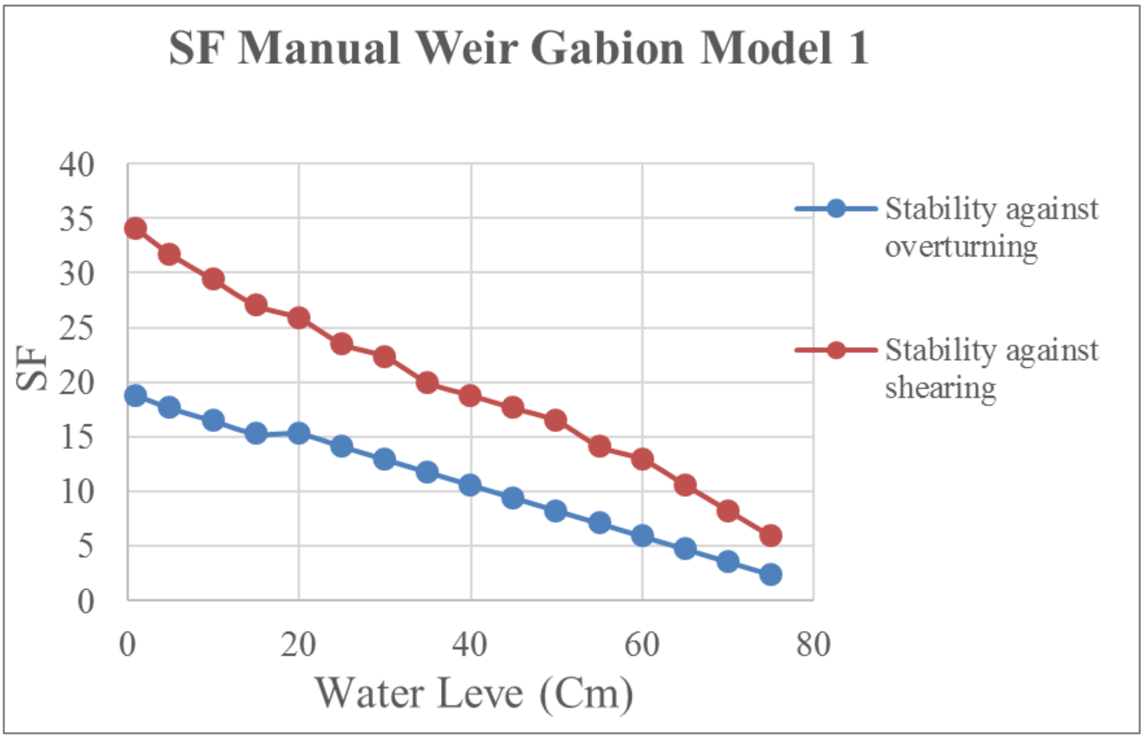

Figure 14. SF Output Graph for Manual Calculation of Overturning Stability and Shear Stability

Software Output Total Displacement from Plaxis HWL can be seen in Figure 15.

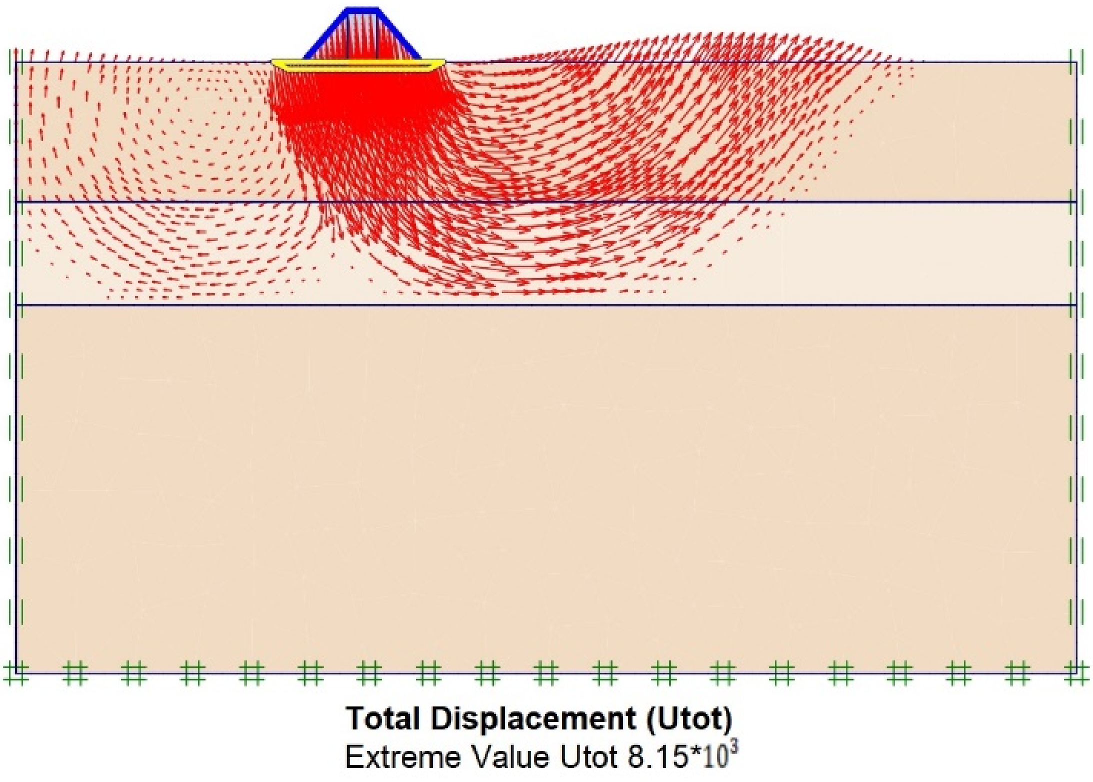

Figure 15. Software Output Total Displacement from Plaxis HWL

Average Voltage of the Plaxis Software Output can be seen in Figure 16.

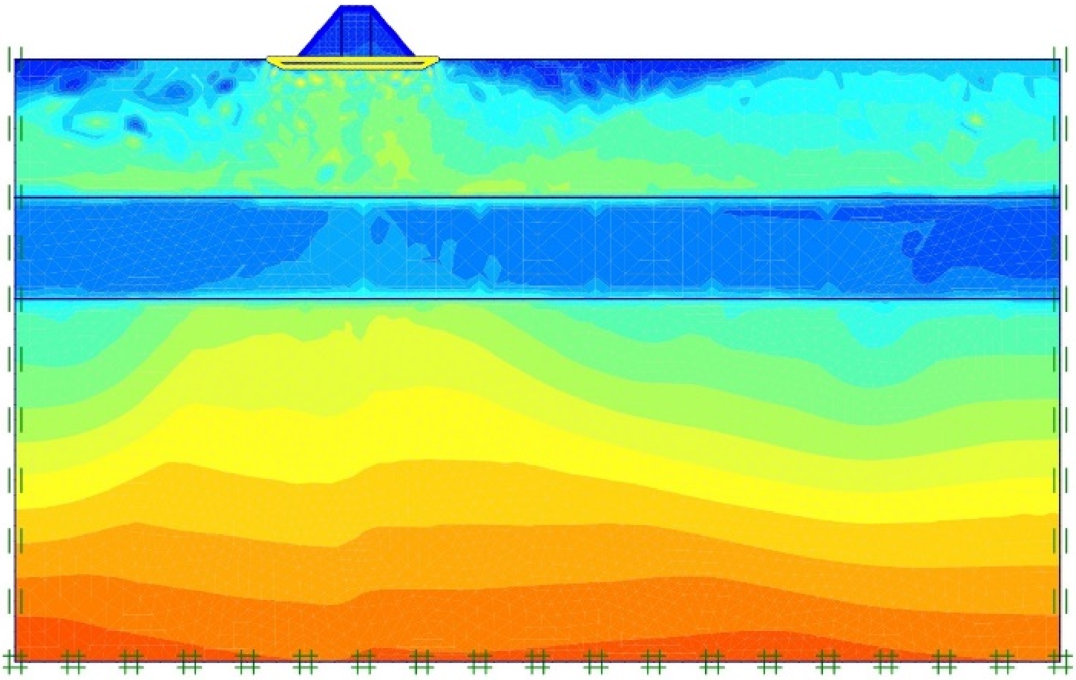

Figure 16. Average Voltage of the Plaxis Software Output

Water Level Analysis for Weir Test

Elevation Water Level Weir Gabion Model 3 can be seen in Figure 17.

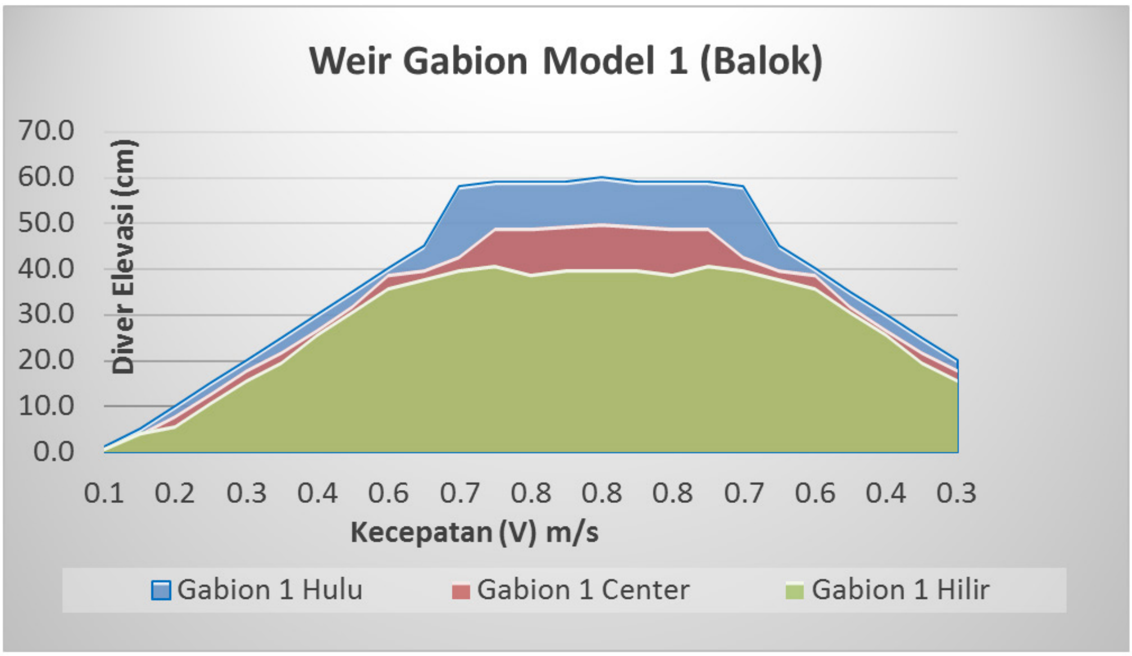

Figure 17. Weir Weir Water Level Model 3 Gabion

1. Weir model 3 shows the observation of the Diver device with the weir elevation value remaining stable. The trial obtained elevation of LWL = 20 cm, MWL= 50 cm and HWL =65 cm.
2. Weir model 3 remains stable against shear and overturning forces when the water reaches High water level = 65 cm.
3. The results of observations using a Current meter device on the flow velocity and temperature of the highest water temperature found the value of the Gabion weir upstream= 1.6 cm/s and 20°C, center = 0.9 cm/s and 15°C, downstream = 0.6 cm/s and 14 °C.
4. In the simulation results using Plaxis software, the safety factor value, it was found that LWL= 4.511 MWL = 4.578, HWL= 4.503 with a total deformation value of 393.94×10^{-3}, effective stress -245,79 KN/m^2.

- Model 4 Trapezoidal Gabion Weir + Geotextile

Model 4 Trapezoidal Gabion Weir + Geotex can be seen in Figure 18.

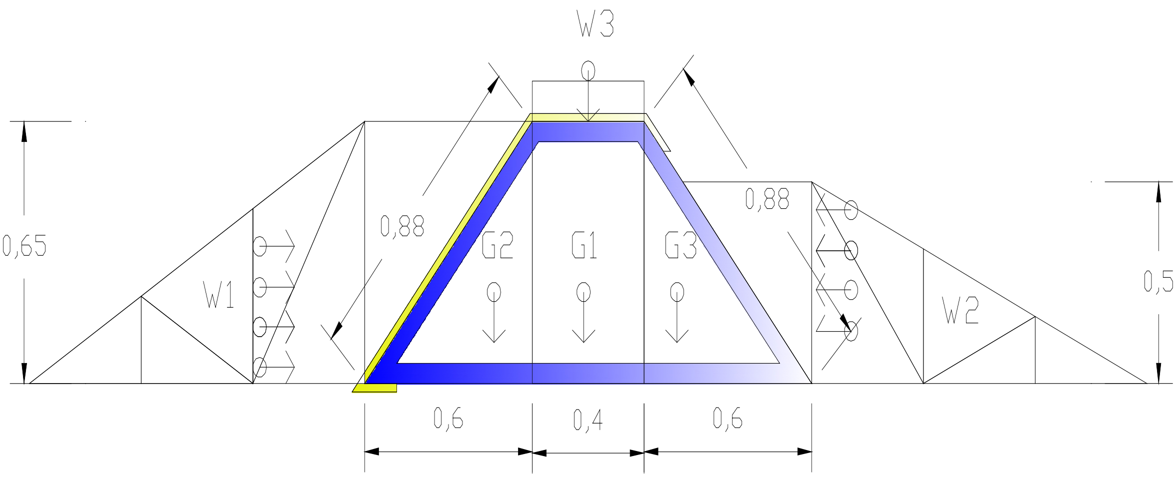

Figure 18. Model 4 Trapezoidal Gabion Weir + Geotex

$$\text{Overturning stability}= \frac{\Sigma MT}{\Sigma MG} \quad \text{Shear Stability}= \frac{fx\Sigma V}{\Sigma h}$$

Overturning Stability and Shear Stability Model 4 Trapezoidal Gabion Weir + Geotex can be seen in Table 4.

Table 4. Overturning Stability and Shear Stability Model 4 Trapezoidal Gabion Weir + Geotex

h (cm)	Stability against overturning	h (cm)	Stability against shearing
1	94.761	1	116.297
5	55.995	5	68.486
10	51.688	10	64.610
15	47.380	15	58.579
20	43.073	20	55.133
25	38.766	25	51.688
30	34.458	30	45.227
35	30.151	35	43.073
40	25.844	40	42.642
45	25.413	45	38.766
50	22.398	50	37.474
55	21.537	55	30.151
60	17.229	60	19.383
65	12.922	65	16.798
70	5.169	70	13.783
75	4.307	75	9.476

SF Output Graph for Manual Overturning and Shear Stability Calculations can be seen in Figure 19.

Overturning stability & Shear stability

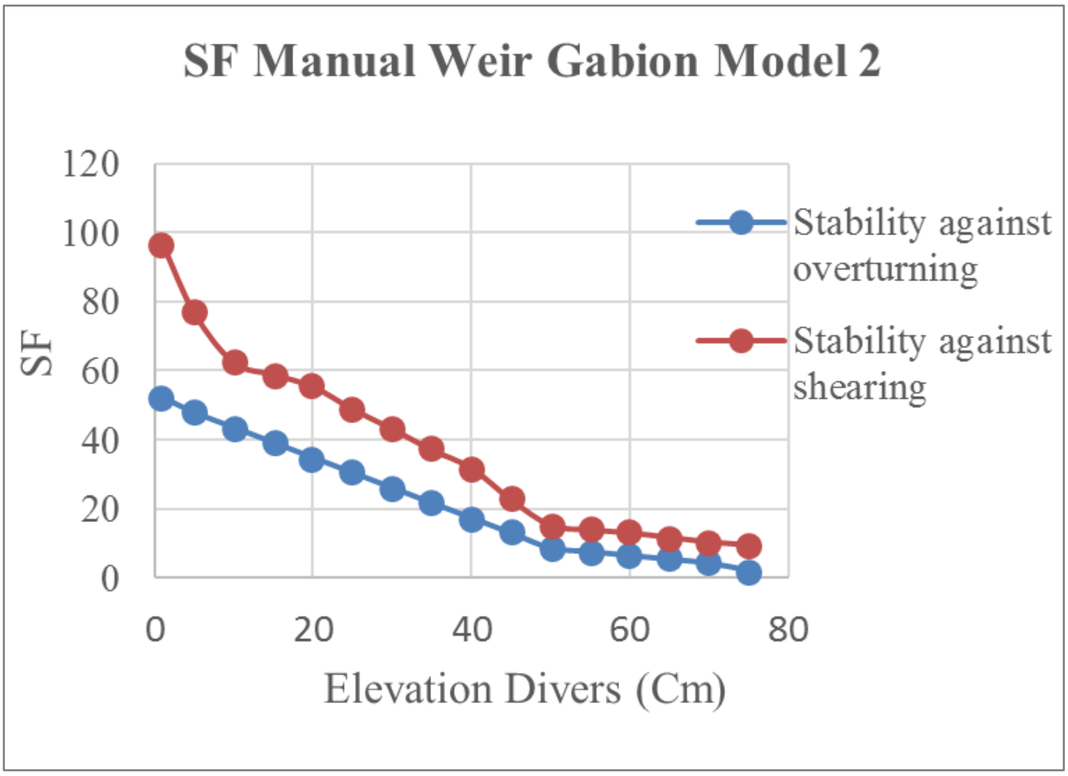

Figure 19. SF Output Graph for Manual Overturning and Shear Stability Calculations

Plaxis Software Output Total Displacement HWL (High Water Level) can be seen in Figure 20.

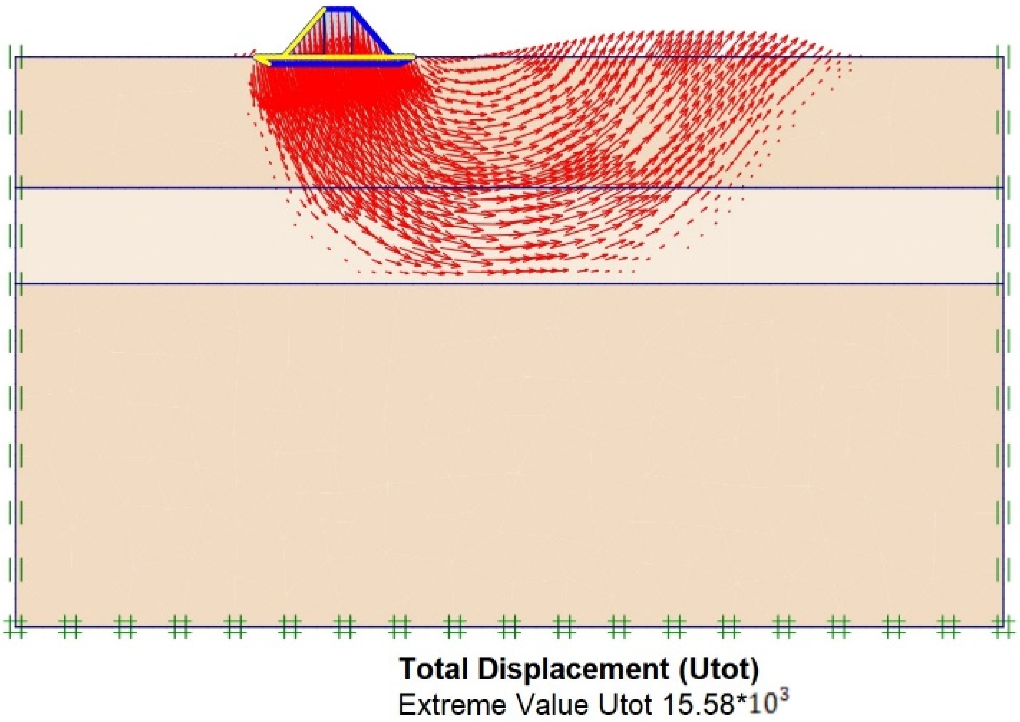

Figure 20. Plaxis Software Output Total Displacement HWL

Average Voltage HWL of the Plaxis Software Output can be seen in Figure 21.

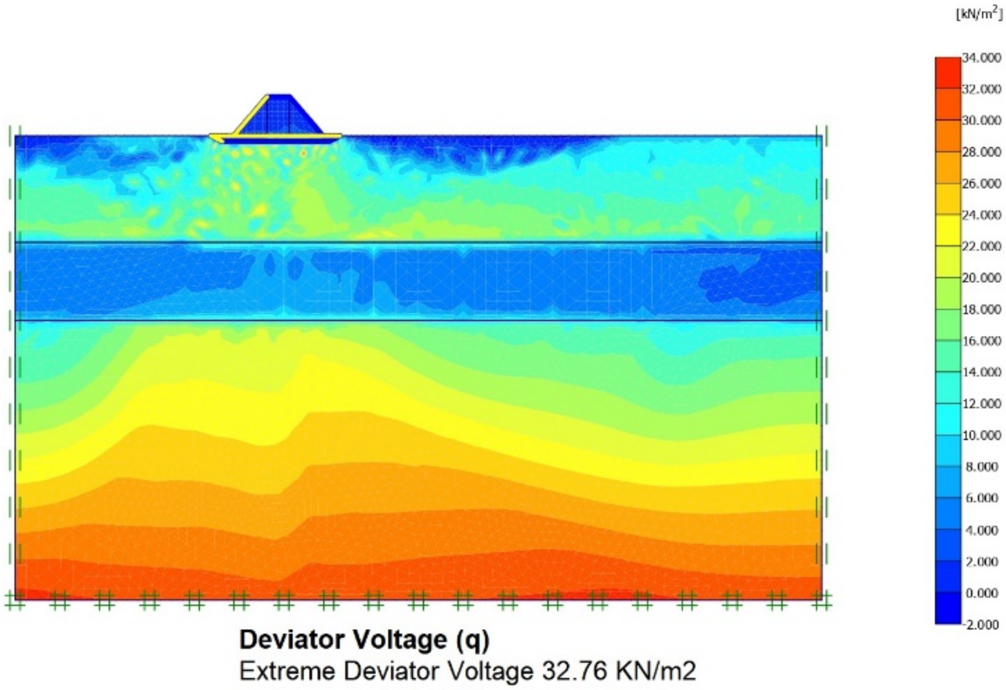

Figure 21. Average Voltage HWL of the Plaxis Software Output

Water Level Analysis for Weir Test

Elevation Water Level Gabion Weir Model 4 can be seen in Figure 22.

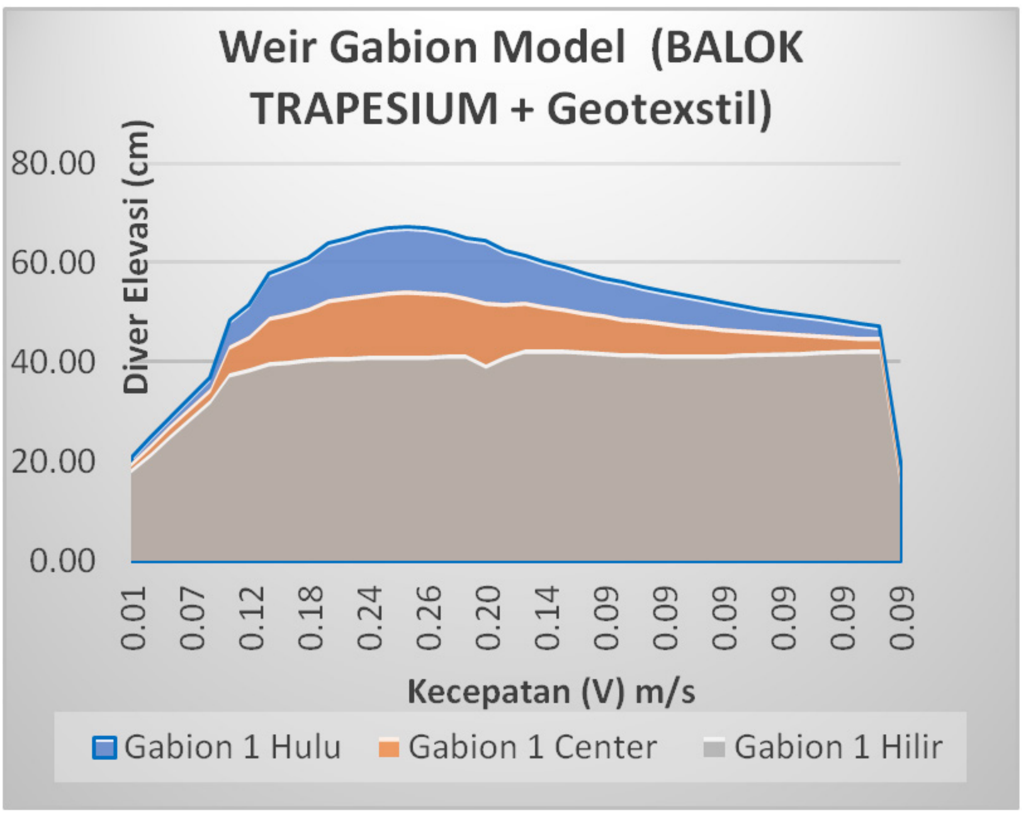

Figure 22. Elevation Water Level Gabion Weir Model 4

1) Weir model 4 shows observations of the Diver device with the weir elevation value remaining stable. In the trial, it was found that the elevation of LWL= 20 cm, MWL= 50 cm and HWL= 70 cm.
2) Weir model 4 remains stable against shear and overturning forces when the water reaches High water level= 70 cm.
3) The results of observations using a Current meter device on the flow velocity and temperature of the highest water temperature found the value of the Gabion weir upstream= 1.6 cm/s and 20°C, center = 0.9 cm/s and 15°C, downstream = 0.6 cm/s and 14 °C.
4) In the simulation results using Plaxis software, the safety factor value, it was found that

LWL =4.472, MWL=4.242, HWL= 4.07 with a total deformation value of 393.94x 10^{-3}, effective stress -245,79 KN/m^2. Recapitulation of Weir Stability Calculation can be seen in Table 5.

Table 5. Recapitulation of Weir Stability Calculation

Condition	Value of Safety Factor (SF) Plaxis			
	Model 1	Model 2	Model 3	Model4 (Geotex)
Construction	1.2942	4.3151	4.7986	4.5076
HWL	1.1740	4.3594	4.5030	4.3071
MWL	1.1986	4.3401	4.5789	4.2418
LWL	1.2011	4.6529	4.5112	4.4722

Table 5 shows that the best weir stability in HWL and MWL is obtained in Model 3 with a value of 4.5030 and 4.5789, while the best weir stability in LWL is Model 2 with a value of 4.6529.

5. Conclusion and Suggestion

Conclusion

Research on the Gabion weir as an appropriate technology alternative to successfully overcome the problem of tidal flood mitigation or as a raw water filter. The design of the Gabion weir model as a filter includes three types of weir testing models, namely the trapezoidal type 1 model, the type 2 beam model, and the type 3 combination model. The results of the analysis of the Gabion weir observation obtained that an average water level elevation, MAR = 10 cm, MAB 60 cm, MAN = 45 cm, elevation of MAB upstream of weir = 65 cm, elevation of center of weir = 44.5 cm, weir downstream of MAB = 41 cm, the water elevation upstream, inside and downstream of the experimental porous weir is in accordance with the initial hypothesis. The water measured flow velocitiesy are in upstream of weir 0.75 l/s, center of 0.75 l/s, downstream 0.6 l/s, and upstream temperature 31°C, center 30.3°C, 30°C, and downstream water conditions are clean. The best weir stability at HWL and MWL was obtained in Model 3 with a value of 4.5030 and 4.58789, while the best weir stability at LWL was Model 2 with a value of 4.6529.

Suggestion

In view of the fact that as a filter, the developed prototype of the gabion weirs shall use good quality materials in such a way that the gabion weir is safe against the acting forces with the purpose that it will be valid in research.

REFERENCES

[1] D. E. Reeve, A. A. Zuhaira, and H. Karunarathna, "Computational investigation of hydraulic performance variation with geometry in gabion stepped spillways," *Water Sci. Eng.*, vol. 12, no. 1, pp. 62–72, 2019, doi: 10.1016/j.wse.2019.04.002.

[2] A. Parwanti, S. I. Wahyudi, and M. F. Niam, "Analysis of Knock-Down Weir Model Shear Stability against Wall Rudeness based on Soil Type Variation," *Civil Engineering and Architecture*, vol. 10, no. 3, pp. 1081–1090, May 2022, doi: 10.13189/cea.2022.100324.

[3] M. Zainuri, M. Helmi, M. G. A. Novita, H. P. Kusumaningrum, and M. Koch, "Improved Performance of Geospatial Model to Access the Tidal Flood Impact on Land Use by Evaluating Sea Level Rise and Land Subsidence Parameters," *J. Ecol. Eng.*, vol. 23, no. 2, pp. 1–11, 2022, doi: 10.12911/22998993/144785.

[4] S. I. Wahyudi *et al.*, "Assessment of polder system drainage experimentation performance related to tidal floods in Mulyorejo, Pekalongan, Indonesia," *Int. J. Integr. Eng.*, vol. 11, no. 9 Special Issue, pp. 73–82, 2019, doi: 10.30880/ijie.2019.11.09.008.

[5] S. I. Wahyudi, H. P. Adi, E. Santoso, and R. Heikoop, "Simulating on water storage and pump capacity of 'kencing' river polder system in Kudus regency, Central Java, Indonesia," in *AIP Conference Proceedings*, 2017, vol. 1818, doi: 10.1063/1.4976928.

[6] K. Huang *et al.*, "Risk analysis of flood control reservoir operation considering multiple uncertainties," *J. Hydrol.*, vol. 565, pp. 672–684, 2018, doi: 10.1016/j.jhydrol.2018.08.040.

[7] A. Shariq, A. Hussain, and Z. Ahmad, "Discharge equation for the gabion weir under through flow condition," *Flow Meas. Instrum.*, vol. 74, 2020, doi: 10.1016/j.flowmeasinst.2020.101769.

[8] G. Brunet, P. Di Pietro, M. De Fátima Souza Curi, K. Tamada, and G. Fracassi, "Hydraulic tests on gabion weirs to develop design criteria for dissipation basins," in *Proceedings of Conference - International Erosion Control Association*, 2005, pp. 83–92.

[9] N. N. Rahma, M. Maryono, and W. Widjanarko, "Introduction Study of Tidal Flood Waste Management

Cost in North Semarang Sub-District," in *E3S Web of Conferences*, 2019, vol. 125, doi: 10.1051/e3sconf/201912507020.

[10] I. Rudiarto, H. Rengganis, A. Sarasadi, and E. Caesar, "The Effectiveness of Strategy Adaptations on Tidal Flood in the Coastal Areas of Sayung, Demak, Central Java, Indonesia," in *IOP Conference Series: Earth and Environmental Science*, 2020, vol. 448, no. 1, doi: 10.1088/1755-1315/448/1/012090.

[11] R. Mohammadpour, A. A. Ghani, and H. M. Azamathulla, "Numerical modeling of 3-D flow on porous broad crested weirs," *Appl. Math. Model.*, vol. 37, no. 22, pp. 9324–9337, 2013, doi: 10.1016/j.apm.2013.04.041.

[12] F. Salmasi and M. T. Sattari, "Predicting discharge coefficient of rectangular broad-crested gabion weir using M5 tree model," *Iran. J. Sci. Technol. - Trans. Civ. Eng.*, vol. 41, no. 2, pp. 205–212, 2017, doi: 10.1007/s40996-017-0052-5.