American Journal of Civil Engineering
2024; 12(1): 27-31
http://www.sciencepublishinggroup.com/j/ajce
doi: 10.11648/j.ajce.20241201.14
ISSN: 2330-8729 (Print); ISSN: 2330-8737 (Online)

Structural Performance Evaluation of Diversion Weir Structure: Case Study of Basaka Small Scale Irrigation Scheme, Oromia, Ethiopia

Gemechu Mosisa

Department of Hydraulic and Water Resource Engineering, College of Engineering and Technology, Wallaga University, Nekemte, Ethiopia

Email address:
ansifgemechu1995@gmail.com

To cite this article:
Gemechu Mosisa. (2024). Structural Performance Evaluation of Diversion Weir Structure: Case Study of Basaka Small Scale Irrigation Scheme, Oromia, Ethiopia. *American Journal of Civil Engineering*, *12*(1), 27-31. https://doi.org/10.11648/j.ajce.20241201.14

Received: December 26, 2023; **Accepted**: January 11, 2024; **Published**: January 23, 2024

Abstract: Diversion weir structures are constructed to withdraw a portion of the stream flow to meet the different water demands to the required place and quantity. These structures, though physically seem small pieces of engineering work, the consideration for structural analysis makes their design complex. Primary data included field observations and measurements, while secondary data included design documentation. In the design, the summation of vertical forces (shear resistance) was more than the summation of horizontal forces (Fh) in the dynamic and static case in the Basaka diversion weir. For this reason, the factor of safety against sliding was determined to be 5.9 and 4.3 respectively which is greater than the optional value (i.e.1). In the design, the resisting moment (Mr) is greater than that of the destabilizing moment (Md) in the dynamic and static case in the Basaka diversion weir. For this reason, the factor of safety against overturning was determined to be 2.5 and 2.1 respectively which is greater than the optional value (i.e.2); this indicates that the weir was safe against overturning. Basaka diversion weir was checked for stability against overstressing for dynamic and static conditions on the site at the time of the study is 0.34 and 0.29 respectively; the result indicates that the structure was safe against tension for the selected condition which is greater than the optional value (i.e. B/6) at designed bottom width. Performance evaluation revealed that the designed weir cross-section of Basaka was accommodating peak flood. In general, the constructed weir has no more engineering design problems that cause low performance but with a lack of well scheme administration, the major problems occurred as field observation results indicate.

Keywords: Overturning, Performance Indicators, Sliding, Tension, Weir

1. Introduction

Diversion weirs are one type of hydraulic structure that supplies water to the off-taking canals and are constructed across a river for the purpose of raising the water level in the river [1–3]. They are costly structures due to their usually massive structural volume. The parameters of the components of this structure are interrelated and are set based on various considerations of surface and subsurface hydraulic and geologic conditions [4–6]. The main purposes of diversion weirs are to raise the water level at the head of the canal, to control the intake of water into the canal, to control the entry of silt into the canal, and to control the deposit of silt at the head of the canal, to store water for a small period of time so that water is available throughout the year, and to control the fluctuation of water level in the river during a different season [2, 3]. As described in previous study weir collapses have been observed over the years, initially unknown due to unbalanced moments, but mainly due to foundation leaching [3]. Stability analysis becomes important when the structure and skirt are made of two different materials and as two separate entities, i.e. when the structure is erected on alluvial soil, not as a whole or as a separate scheme [4, 5]. For those cases where structural components are designed based on surface and subsea flow considerations, a stability check should be performed on the structure [7–9]. The forces and moments acting on the corresponding structure are then calculated and the stability of the structure is checked against overturning, tension, and sliding [4, 5, 9–11]. If a structure is uncertain about its condition at the time of assessment, the cause must be investigated [12–14]. Due attention is paid to the forces acting on the diversion structure, especially the weir section, therefore, the diversion weir as a whole should be structurally safe and stable. If the structure is unsafe for the condition at the time of assessment the reason shall be studied. The forces that act on the diversion structure, specifically the weir section has given due attention [8, 9]. The performance indicators designated for this study were stability against tension, overturning, and sliding [4, 5, 8, 9, 11]. The goal of the current study was to analysis of the stability of the weir body against tension, sliding, and overturning for dynamic and static conditions.

2. Materials and Methods

2.1. Location and Description of the Study Area

The study was conducted at the Basaka diversion weir which is located in Gida Basaka Kebele, Wayu Tuka Woreda, East Wallaga zone, Oromia region, Ethiopia. Wayu Tuka woreda is located about 324km from West of Finfinnee (Addis Ababa city) at maximum and minimum altitudes of 2200m and 1700m a.m.s.l respectively. The geographical location of the study area is at latitude 8°57′30"N to 9°0′0"N and longitude of 36°34′30" E to 36°40′ 30" E. The location of this study area is shown in Figure 1.

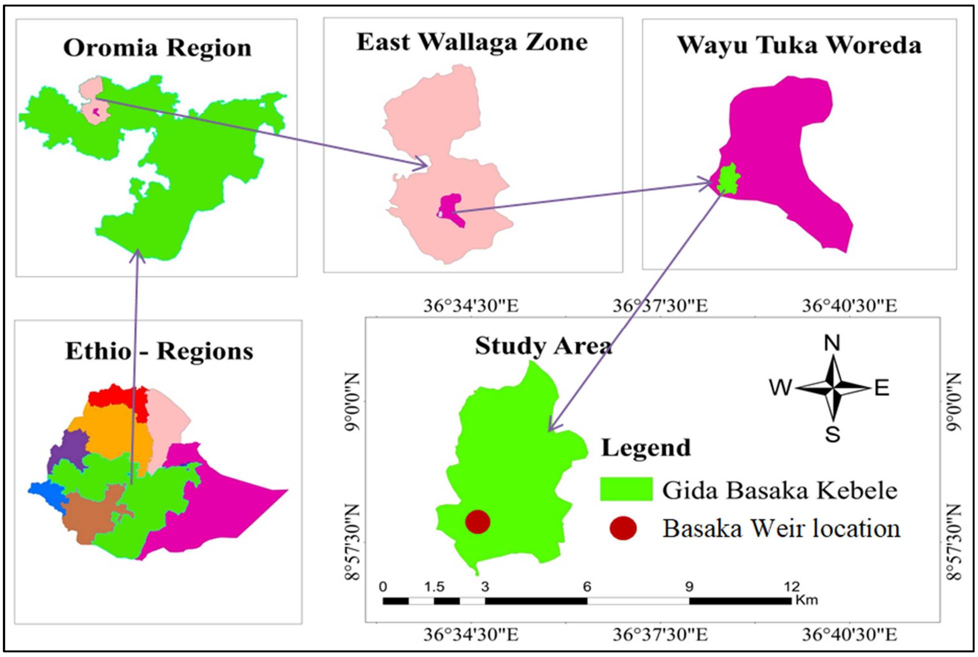

Figure 1. *Location map of the study area.*

2.2. Data Sources

There are two sources of data. Those are primary and secondary data sources.

2.3. Method of Data Collection

Direct field measurements of the actual external weir dimension concerning primary data, secondary data such as feasibility of the design document for a Basaka diversion weir taken from the East Wallaga Zone Irrigation Development Office, engineering manuals, engineering structures, journals, other published, and unpublished subject materials were used.

Table 1. *Summary of Basaka weir dimensions.*

Diversion Weir	Weir Length	Weir height	Overflow water depth	Top thickness(T)	Bottom thickness(B)
	m	m	m	m	m
Basaka	14.5	1.5	1	1	2

Table 2. *Constant Parameter during structural analysis of the weir body.*

Unit weight of materials			
Symbol	**Parameters**	**Unit**	**Value**
γc	Unit weight of concrete	KN/m^3	24
γw	Unit weight of water	KN/m^3	10
γs	Specific weight of silt	KN/m^3	18
γs	Unit weight of saturated	KN/m^3	18
ϕ	Angle of internal friction of material	Degree	30
Ka	Active pressure coefficient	-	0.33

2.4. Structural Performance Indicator Analysis of Basaka Diversion Weir

As indicated in [15] it has been observed over the years that diversion weirs collapse, initially not because of the unbalanced moment, but mainly due to the foundation scouring. The stability analysis becomes important where the structure and the apron are of two different materials and act as two independent units, i.e. non – monolithically or as particular schemes that structure is built on alluvial soil. For such cases designing the components of the structure based on the surface and sub-surface flow considerations, the structure should have to be checked for stability. The force and the moment acting on the corresponding structure are then calculated and the structure is checked for its stability against overturning and sliding. If the structure is unsafe for the condition at the time of assessment the reason shall be investigated [7, 8, 14]. The forces that act on the diversion structure, especially the weir section have given due attention. Therefore, the diversion headwork as a whole should be structurally safe and stable. The structural performance indicators selected for this research work are stability against, overturning, and sliding. At the last step in the design procedure of the diversion weir, the stability of the structure should be checked against various threats such as safety against sliding, safety against overturning taking into consideration every involved and related parameter in each case [7, 8, 16].

Stability analysis was carried out on the structure for the most severe conditions of horizontal and vertical forces. Stability criteria are aimed at certifying the overall safety of the structure against overturning, tension, and sliding. The forces which are applied on the diversion weir as indicated in the Figure 2.

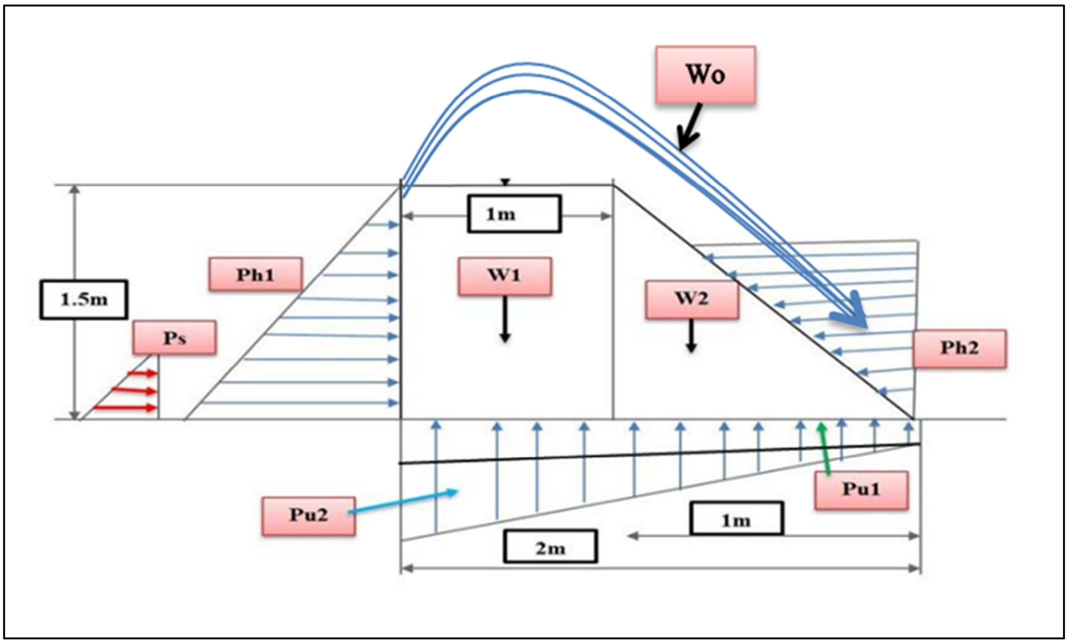

Figure 2. *Forces and moments acting on weir at dynamic and static case.*

2.4.1. Stability against Overturning

It is a significant factor to take into consideration occurs when the overturning (destabilize) moment exceeds the resisting (stabilize) moment. The safety factor of wall stability against overturning is the ratio between the sum of resisting moments and the sum of overturning moments. In evaluating these moments, the vertical component of the active thrust on the wall may be considered in two different ways: as decreasing the overturning moment or increasing the resisting one [8, 9].

$$F_o = \frac{\sum M_r}{\sum M_d} \geq 2 \quad (1)$$

Where: Fo - is a factor of safety against overturning, Mr - is the resisting moment, and Md -is the destabilizing moment.

2.4.2. Stability against Sliding

The aprons and the weir body should have to be checked for stability against sliding. If there are not enough holds between the base and foundation; the structure may slide in the flow direction. To prevent this problem, the vertical forces are checked to be adequate as compared to the horizontal forces, to supply static friction that would keep the structure intact in its place. The weir should be designed so that the sliding forces do not exceed the resisting force [6, 8, 11].

$$F_s = \frac{\sum F_v}{\sum F_h} \geq 1 \quad (2)$$

Where: Fs = is a factor of safety against sliding, Fv = Is the vertical forces, and Fh = is the horizontal forces.

2.4.3. Stability against Tension

Stability against tension occurred if the resultant force is not passing through the middle third section of the base [6, 10].

$$e \leq \frac{B}{6} \quad (3)$$

$$e = X - \frac{B}{2} \quad (4)$$

$$X = \frac{\sum M_n}{\sum F_v} \quad (5)$$

$$M_n = \sum M_r - \sum M_d \quad (6)$$

Where: Mn is the net moment, e is eccentricity and B is the base of weir in m.

3. Results & Discussion

3.1. Stability Check on Diversion Weir at Dynamic Case

Table 3. *Forces and moments acting on weir at dynamic case.*

S. No	Name of forces	Designation of forces	Formula to be used	Description	Magnitude of force in (KN)		Lever arm about B in (m)	Moment in KN.m	
					Horizontal	Vertical		Md	Mr
1	Self-weight of the weir	W1	γc*Ac	1 *1*1.5 *24		36	1.5		54
		W2	0.5γc*Ac	$\frac{1}{2}$*1*1.5 *1 *24		18	0.7		12.6
2	Horizontal water forces at u/s & d/s respectively	Ph1	0.5γw*hw1^2	$\frac{1}{2}*1.5^2*1*10$	-11.3		0.5	5.7	
		Ph2	0.5γw*hw2^2	$\frac{1}{2}*1.15^2*1*10$	6.6		0.38		2.5
3	weight of over flow water	Wo	γw*ho*T	1 *1 *1 x*10		10	1.5		15
4	*Psilt*	Ps	0.5Ka*γs*hs^2	$\frac{1}{2}*0.33*0.2^2*1*18$	-1.7		0.25	0.43	
5	Uplift pressure	UP1	γw*hw1*B	2 * 1.15 *1* 10		- 23	1	23	
		UP2	0.5γw*(hw1-hw2)*B	$\frac{1}{2}$*2 * 0.35 *1* 10		-3.5	1.3	4.6	
Summation					-6.4	37.5		33.73 ΣMn	84.1 50.73

Table 4. *Forces and moments acting on weir at dynamic case.*

Condition	ΣV	ΣH	$ΣM_r$	$ΣM_d$	ΣMn
	KN	KN	KN.m	KN.m	KN.m
Dynamic case	37.5	-6.4	84.1	33.73	50.37

3.2. Stability Check on Diversion Weir at Static Case

Table 5. *Forces and moments acting on weir at static case.*

S. No	Name of forces	Designation	Formula to be used	Description	Magnitude of force in (KN)		Lever arm about B in (m)	Moment KN.m	
					Horizontal	Vertical		Md	Mr
1	Self-weight of the weir	W1	γc*Ac	1 *1*1.5 *24		36	1.5		54
		W2	0.5γc*Ac	$\frac{1}{2}$*1*1.5 *1 *24		18	0.7		12.6
2	Horizontal water forces at u/s & d/s	PW1	0.5γw*hw1^2	$\frac{1}{2}*1.5^2*1*10$	-11.3		0.5	5.7	
		PW2	0.5γw*hw2^2	$\frac{1}{2}*1.15^2*1*10$	6.6		0.38		2.5
3	*Psilt*	Ps	0.5Ka*γs*hs^2	$\frac{1}{2}*0.33*0.2^2*1*18$	-1.7		0.25	0.43	
4	Uplift pressure	UP1	γw*hw1*B	2 * 1.15 *1* 10		-23	1	23	
		UP2	0.5γw*(hw1-hw2)*B	$\frac{1}{2}$*2 * 0.35 *1* 10		-3.5	1.3	4.6	
Summation					-6.4	27.5		33.73 ΣMn	69.1 35.37

Table 6. *Forces and moments acting on weir at static case.*

Condition	ΣV	ΣH	$ΣM_r$	$ΣM_d$	ΣMn
	KN	KN	KN.m	KN.m	KN.m
Static case	27.5	-6.4	69.1	33.73	35.37

Table 7. Summary of structural analysis calculation results of the two cases.

Stability analysis of Basaka diversion weir				
Condition	**Safe against Overturning**	**Safe against Sliding**	**Overstress(tension)**	$\frac{B}{6}$
For the case of dynamic	2.5	5.9	0.34	0.5
For the case of static	2.1	4.3	0.29	0.5
Conditions to be satisfied	Fo ≥ 2	Fs ≥ 1	< B/6	

4. Conclusion

In this study, the structural performance evaluation of the Basaka diversion weir has been dealt with through field investigation findings and various measurements held on the field and a review of the design document and various related resource materials. The performance evaluation analysis has covered only the diversion weir structure. A structural analysis was conducted as a result, and it was determined to be structurally safe. Sedimentation on this bed level comes from the catchment area and is stored in the upstream reservoir due to the lack of under sluice gate structure on this weir. Therefore, the weir height was reduced from 1.5m to 0.75m. However, since the sediment inflow prevention mechanism of the scheme is poor, the flushing method takes a very long time, which reduces the productivity or efficiency of the whole irrigation system.

Data Availability

All information provided to this publication is presented in the full document.

Conflict of Interest

The author declares no conflicts of interest.

References

[1] S. Garg, "Irrigation Engineering And Hydraulic Structures. Khanna Publishers, Delhi. Nineteenth Revised Edition.," 2005.

[2] G. Asawa, "Irrigation And Water Resource Engineering. New Age International Publishers. New Delhi.," 2008.

[3] M. Bibhabasu, "Diversion Head Works, Module. Sal Institute Of Engineering And Reaserch June," 2012.

[4] M. W. Hora, "Assessment Of Design Practices And Performance Of Diversion Weir In Small Scale Irrigation (Case Study From Projects In Western Oromia, Ethiopia)," 2016.

[5] D. K. Temesgen, "Performance Evaluation Of Tibila Irrigation Based Development Project Diversion Headwork, Ethiopia," 2017.

[6] F. Ertiro, S. M. Pingale, And A. N. Wagesho, "Evaluation Of Failures And Design Practices Of River Diversion Structures For Irrigation: A Revisit Of Two Ssi Schemes In Ethiopia," Int. J. Earth Sci. Eng., Vol. 10, No. 03, Pp. 495–505, 2017, Doi: 10.21276/Ijee.2017.10.0305.

[7] F. Gurmecha, "(AASTU) Diversion Weir Design Project (Asher River) Approval Page Members Of The Examining Board :," No. May, 2017.

[8] B. Belango, "Performance Evaluation Of Diversion Headwork Structures For Irrigation: Case Study On Agega-1, Agega-2 And Sana Irrigation Schemes In Kembata Tembaro Zone, Snnpr, Ethiopia," 2021.

[9] B. Sisay, "Assessment Of Design Practices And Performance Of Small-Scale Diversion Weirs Constructed For Irrigation Project (A Case Study Of Ashar And Upper Kuashini Small-Scale Irrigation Schemes In Awi Zone, Dangla Woreda)," 2022.

[10] T. Mulugeta And W. Tadesse, "Assessment Of Irrigation Scheme Failure Factors : A Case Study On Marza Irrigation Scheme Fogera, Amhara, Ethiopia," Water Conserv. Sci. Eng., Pp. 465–474, 2022, Doi: 10.1007/S41101-022-00155-Y.

[11] E. Abel, "Investigation Of Causes Of Diversion Weir Failure (A Case Study On Marza Small-Scale Irrigation Scheme, South Gondar, Ethiopia)," 2021.

[12] K. Dereje, "Performance Evaluation Of Tibila Irrigation Based Development Project Diversion Headwork, Ethiopia," 2017.

[13] A. Endalew, "Investigation Of Causes Of Diversion Weir Failure (A Case Study On Marza Small-Scale Irrigation Scheme, South Gondar, Ethiopia)," 2021.

[14] T. K. Kebede, "Assessment Of Design Practices And Performance Of Diversion Weir In Small Scale Irrigation (A Case Studies In Offiya Irrigation Project)," 2021.

[15] JICA, "Headwork Design Manual," 2010.

[16] H. Fikru, "Performance Assessment Of Diversion Head Works Implemented For Irrigation: Case Of Fentale Irrigation Based Development Project. Msc, Thesis.," 2014.