Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 8, S. 542-551, 2, 2024

Araştırma Makalesi

IJANSER
https://as-proceeding.com/index.php/ijanser
ISSN: 2980-0811

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 8, pp. 542-551, 2, 2024

Research Article

"Design and Implementation of Fuse Gate for efficient flow control and to enhance the storage capacity of Reservoir"

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(Received: 12 March 2024, Accepted: 13 March 2024)

(4th International Conference on Innovative Academic Studies ICIAS 2024, March 12-13, 2024)

ATIF/REFERENCE: Hamza, A., Siddiqi, J. A., Ishaq, N., Haider, M. A., Tahir, A., Anjum, N., Nawaz, B. & Ahmed, Z. (2024). "Design and Implementation of Fuse Gate for efficient flow control and to enhance the storage capacity of Reservoir". *International Journal of Advanced Natural Sciences and Engineering Researches, 8(2), 542-551.*

Abstract– The research aims to evaluate the effectiveness of Fuse Gate technology in increasing the storage capacity of the Rawal Dam while mitigating downstream flooding risks. Rawal Dam, situated on the downstream of the Korang River, has experienced a reduction in storage capacity due to alterations in the river's flow and sedimentation, particularly at the Dead Storage Level (DSL) and Normal Storage Level (NSL). A Hydrographical survey conducted using Google Earth Pro focused on assessing reservoir elevation levels and identifying areas of reduced storage capacity. Mapping terrain between the Right Guide Bank (RGB), Left Guide Bank (LGB), Right Marginal Bund (RMB), and Left Marginal Bund (LMB) was conducted, considering an estimated flood depth of 10m. The diminishing storage capacity poses significant risks to downstream areas, especially during critical months. The research aims to explore the potential of fuse gate/rubber dam technology in enhancing flow control and to mitigate the storage capacity loss of existing low to medium height dams, river management in Pakistan, with the flexibility especially to increase the Rawal Dam's storage capacity loss across the Korang River. This endeavor holds promising benefits, including improved irrigation reliability, water supply, and reduced flood risks in adjacent areas, contributing to both industry and societal welfare.

Keywords – Fuse Gate / Rubber Dam, Rawal Dam, Flood Control, Storage Capacity, Reservoir Stability.

I. INTRODUCTION

Fuse-gate systems are an innovative solution for control flow, protect against floods, and enhance water resource efficiency by maximizing reservoir storage capacity without raising maximum water levels. During flood events, when the dam is full water flows over the crest of the fuse-gate modules, which acts like an un-gated spillway. They're applicable to new and existing dams, reducing construction costs and improving safety [1, 4]. Rawal Dam is one site where fuse gates can be implemented.

Rawal Dam was constructed in 1962 across the Korang River near the village of Rawal, approximately nine miles from Rawalpindi town along the Murree Road, at a longitude of 73°7' and a latitude of 33°41'. In a standard dry year, the rainfall averages 42 inches, and in a mean year, it's 45 inches [2, 5]. The average annual inflow is 84,000 acre-feet, with an average annual sedimentation of 80 acre-feet. The original Live storage capacity of the reservoir is 43,000 acre-feet. The spillway capacity of the dam is 82,000 cubic feet per second at full gate openings, with a spillway width of 275 feet and a clear waterway of 240 feet. Location plan of Rawal dam is shown as in “Figure 1”[3].

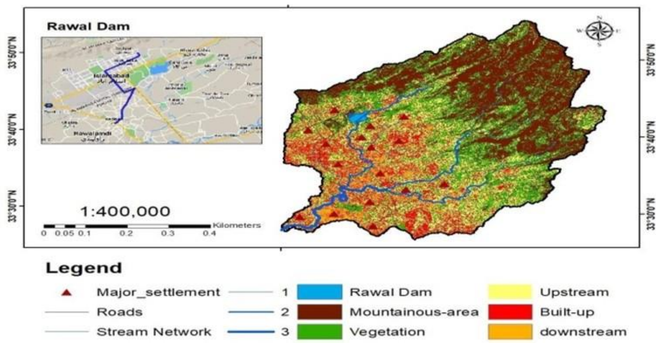

Figure 1.Location plan of Rawal Dam across Korang River [5]

Globally, floods are a devastating hazard that can cause significant damage to property, economies, and human lives. Intense rainfall and the melting of snow and glaciers adding to the volume of water beyond the river's capacity, resulting in overtopping. Pakistan faces a range of hazards, including hydro-meteorological, geological, and biological risks [6, 16].

Flooding, a hydro-meteorological hazard, can result in the outburst of dam lakes [5, 6, 17]. One approach to mitigating downstream flood risk is by expanding reservoir storage capacity [7]. Several methods can achieve this. Firstly, increasing the reservoir's capacity by raising the dam or constructing additional embankments proves effective [7, 8]. Secondly, modifying or adding spillways enhances the dam's ability to control floodwaters and boosts storage capacity [8]. Thirdly, constructing off-stream reservoirs provides supplementary storage to the main dam [9]. Moreover, enhancing the live storage capacity of dams with un-gated Fuse gates without raising the maximum water level is crucial, that improve spillway discharge capacity without compromising existing storage by lowering the spillway crest before installing Fuse gates is another viable strategy [1, 4,13] . Over the years, the storage capacity of Rawal Dam has decreased due to sedimentation [10]. To predict the storage capacity of Rawal Dam, we discovered a strong correlation between storage capacity and water level. Subsequently, we generated a regression model between these parameters, as in “Figure 2”.

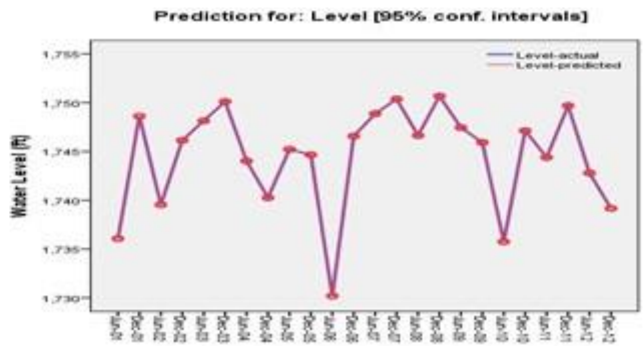

Figure 2. A regression model b/w water level & Month [11]

According to the sedimentation survey of 2019, the reservoir's dead storage level was measured at 1708 feet, while the high flood level was recorded at 1761 feet [12, 14]. A spatial hydrological model was employed to estimate the flood's vertical and horizontal profile downstream in the event of a dam breach, as shown in "Figure 3".

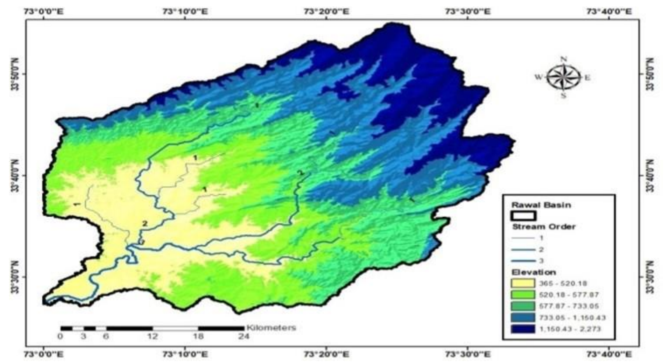

Figure 3. Spatial Hydrographical Model of Dam Breach [5].

The storage capacity of Rawal Dam has 34.16% diminished over time due to sedimentation. The Original designed Live storage capacity of Rawal dam is 43000 Aft. The 2000 sedimentation survey, revealed a reduction in gross storage capacity to 37,397 acre-feet, which further decreased to 28,309 acre-feet by 2019. Now, the dead storage level stands at 1708 feet, the normal reservoir level at 1752 feet, and the high flood level recorded at 1762 feet [4].

This Research aims To avoid sudden and uncontrolled water releases and provide the flexibility to allow water releave rate smoothly and Ensuring the Stability of Dam after the Fuse-Gates were installationed..

The research gap can be identified as the absence of empirical studies or analyses examining the application, effectiveness, and challenges of Fuse Gates in enhancing storage capacity and mitigating downstream flooding risks at the Rawal Dam. Additionally, there is a lack of discussion on the potential challenges, such as hydraulic performance, structural integrity, and environmental considerations associated with the implementation of Fuse Gates in the Rawal Dam reservoir.

Our focus lies in grasping Rawal Dam's conditions, assess its stability, and design a fuse gate system for improving spillway discharge capacity, safety optimization and environmental impact like flood risk reduction. Through meticulous data collection, analysis, and design, it aims to enhance dam resilience, mitigate downstream flood risk, and ensure sustainable water resource management.

II. METHODOLOGY

2.1.Preliminary Assessment and Data Collection:

Extensive efforts were made to gather comprehensive data on various aspects of Rawal Dam, including salient features, hydro-graphic data, reservoir characteristics, dam specifications, and spillway details. Additionally, data provided by the Irrigation department was incorporated into the study include Rawal dam Spillway Gate Opening Data (2011 - 2022) as Shown in "Figure 4".

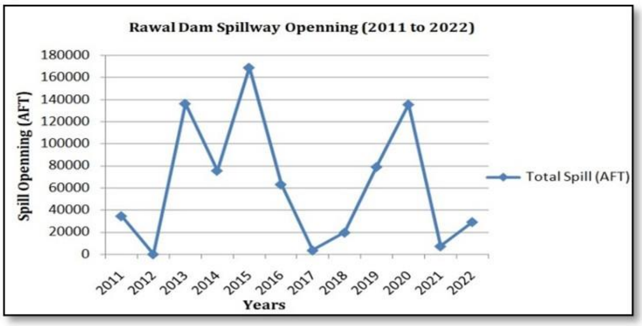

Figure 4. Rawal dam spillway Opening (2011 – 2022)

The initial phase involved rigorous engineering analyses and dam stability calculations to assess resilience under different conditions like overtopping, normal flow, and high flood levels. The hydrographic survey data for Rawal Dam in 2019 was provided by the Irrigation Department as shown in "Figure 5".

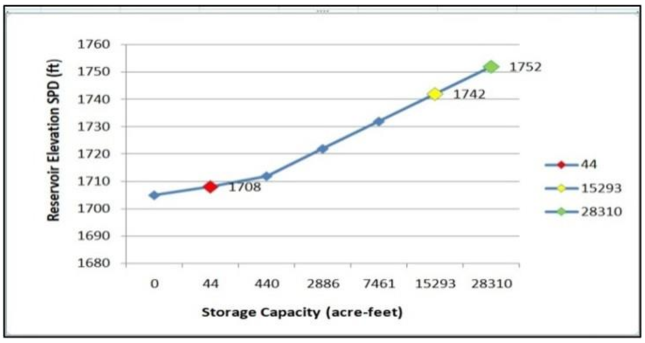

Figure 5. Hydrographic Survey record (2019)

2.2 Field survey:

For this research work, a study was conducted by Topographical and Hydrological Survey of Rawal dam. Utilizing advanced tools such as Google Earth Pro software, a comprehensive topographic survey was carried out. Different elevation levels of hydrographic data were obtained and utilized to create a detailed terrain model of Rawal Dam using Hecrass software. This detailed survey data, combined with manual calculations and analyses, facilitated the design of the fuse gate system aimed at enhancing the reservoir's storage capacity.

2.3 Design Phase:

Based upon the preliminary assessment, a meticulous design process was undertaken for the fuse gate system. Factors such as reservoir capacity, normal flow level, high flood level, and environmental impact were carefully considered. The primary objective was to optimize dam safety while mitigating downstream flooding risks. Manual calculations and computational tools like Excel were utilized to analyze the dam stability and discharge characteristics. Various factors, including reservoir capacity, downstream overtopping and safety protocols were carefully accounted for during the design calculations. This ensured that the resulting design would effectively fulfill project objectives while adhering to safety and environmental standards. After Ensuring the Stability of Dam and Fuse gate A 2D and 3D Model of Fuse gate is made by utilizing advanced tools of Auto-cad software, Sketchsoftware, Sketch-up and V-ray.

III. RESULTS

This study's main goal, I was to design of fuse gate/ rubber dam and ensure stability of infrastructure for efficient flow control of site across Rawal dam, improving spillway discharge capacity to Prevent from the risk of downstream Flooding. The hydro-graphical survey employed advanced tools and Google Earth Pro software to gather elevation data for Rawal Dam. This data is crucial for accurately representing the ground surface, impacting water movement in the flood plain. It can be utilized in various applications such as visualizing floodplain geometry and preprocessing geometric data for 2D Flow Areas and inundation boundaries from simulation results. Additionally, a 2D modulation of the fuse gate at Rawal Dam was created using Auto-cad, depicting different forces and pressures acting on the dam.

3.1 Hydrographical Survey :

A hydro-graphical survey was taken with the help of advanced survey tools by Utilizing Google Earth Pro software. The results of elevation levels for the area of Rawal Dam are given as shown in "Figure 6".

Figure 6. Hydrographic Survey using Google Earth Pro

3.2 Topographical Survey and Terrain Formation:

A good terrain model represents the ground surface well in locations that affect the movement of water through the flood plain.Terrain data can be used in RAS to visualize the floodplain geometry. It is additionally utilized in preparing geometric data for 2D flow areas and inundation boundaries derived from simulation outcomes.

3.3 2D Design Model Simulation Of Fuse Gate :

A 2D Modulation of Fuse Gate Made Using Advanced tools and Softwares Utilizing Autocad following Section of Rawal Dam with Fuse Gate is Shown in "Figure 7".

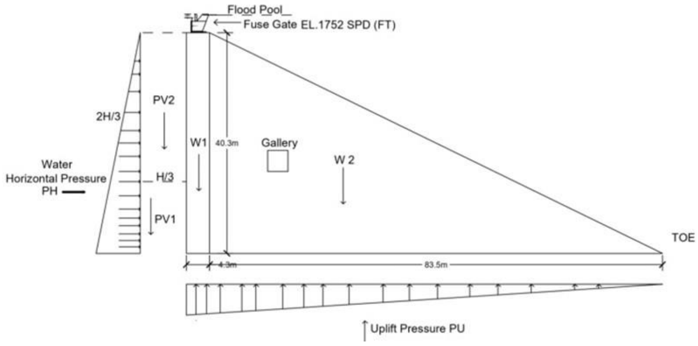

Figure 7. 2d Section Model Simulation Fuse Gate on dam

A schematic Section of Rawal Dam with Installation Of Fuse gate showing Different Forces and Pressures that act on Dam.Where H is height of Fuse Gate and in Our Calculations we choose H=2.15m as shown in "Figure 8".

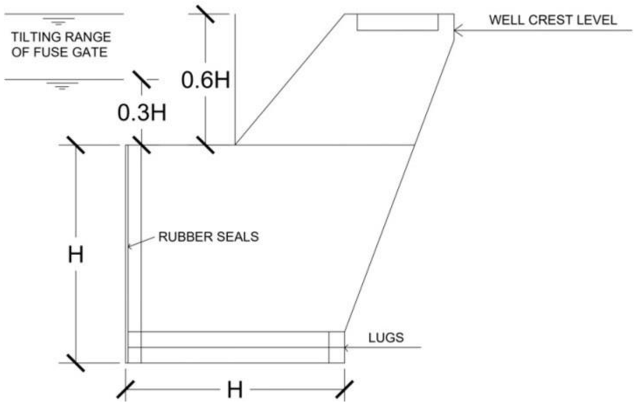

Figure 8. Fuse-Gate 2D Simulation

3.4 Rawal Dam Stability Before Installing Fuse Gate:

Before Installing the Fuse Gate to Analyze the stability of dam, All the Resting moments and all overturning Moments are calculated.

Table 1.

Moment Calculations of Rawal Dam Korang River (1962)						
Forces	**Vertical Force (KN)**	**Horizontal Force (KN)**	**Lever Arm**	**Resting Moment (MR) (KN-m)**	**Overturning Moments (MO) (KN-m)**	**Remarks**
Weight 1	4200.24		85.65	359750.6		PV1 and Pv2 are Vertical pressures while PU and PH are Uplift and Horizontal Pressure Respectively.
Weight 2	40781.4		55.7	2270164.6		
PV1	133.089		114.9	15296.4		
PV2	266.178		101.37	26981.6		
PU(-ve)		17527.82	58.5		1025961.80	
PH (-ve)		8125.083	13.6		110230.298	
Total	45380.90	25652.90		2672193.095	1136192.106	
	Note: Resting moment > Overturning Moment			So, the dam is in safe limit.)		

Other Calculations					
Description	**Formula**	**Calculation**	**Results**	**Conclusion**	**Remarks**
E-centricity of resultant forces	E=B/2-X	10.1	ok	safe	Where u=0.65 – 0.75 and q=1400
Factor of Safety against Tension	E<(B/6)	14.6	10.5<14.6	safe	
F. Safety against Overturning	Sum(Mr/Mo)>2	2.35	2.31>2	safe	
F. Safety against Sliding	(u*Fv+B*q)/FH)>1	5.92	5.92>1	safe	
Angle from toe	Alpha=tan-1(prep/base)	25.98			
Resting Moment > Overturning Moment	Mr> Mo	2673011>1158198		safe	

3.5. Rawal Dam Stability After Installing Fuse Gate:

After Installing the Fuse Gate to Analyze the stability of dam, All the Resting moments and all overturning Moments are calculated as follows:

Table 2.

Rawal Dam (1962) with 2.15m Height of Fuse gate						
Moment Calculations						
Forces	**Vertical Force (KN)**	**Horizontal Force(KN)**	**Lever Arm**	**Resting Moment (MR) (KNm)**	**Overturning Moments (MO) (KNm)**	**Remarks**
Weight 1	4422.12		85.65	378754.6		PV1 and Pv2 are Vertical pressures while PU and PH are Uplift and Horizontal Pressure Respectively.
Weight 2	42935.7		55.7	2390087.3		
PV1	140.1195		116.4	16305.2		
PV2	280.239		102.08	28607.7		
PU(-ve)		18453.74	58.5		1080158.806	
PH (-ve)		9006.181	14.3		128638.283	
Total	**47778.17**	**27459.92**		**2813754.84**	**1208797.09**	
	Note:	**Resting moment > Overturning Moment**		(So, the dam is in safe limit.)		

Other Calculations					
Description	**Formula**	**Calculation**	**Results**	**Conclusion**	**Remarks**
E-centricity of resultant forces	E=B/2-X	10.3	ok	safe	Where u=0.65 – 0.75 and q=1400
Factor of Safety against Tension	E<(B/6)	14.6	10.3<14.6	safe	
F. Safety against Overturning	Sum(Mr/Mo)>2	2.33	2.33>2	safe	
F. Safety against Sliding	(u*Fv+B*q)/FH)>1	5.69	5.69>1	safe	
Angle from toe	Alpha=tan-1(prep/base)	25.98			
Resting Moment > Overturning Moment	Mr> Mo	2814624.7>1232209		safe	

3.6 Stability of Fuse Gate itself After Installation:

Table 3.

Fuse Gate Stability						
Sr	Description	Formula	Calculation	Unit	Calculated some other data	
1	Overtopping discharge	2/3*(2g)^1/2* cg*h 3/2*lc	23.8	m3/sec	**Gate Moment**	
2	Sliding	Fs=Fs1+Fs2	1726.17	KN	**ps**	2400 kg/m3
3	Upstream Moment	Ms=Ms1+Ms2	1528.95	KNm	**vs**	5.77 m3
4	Uplift Moment	Mu=Pw*g*Ac*Hw*Yu	685.44	KNm	**ys**	3.29 m
5	Gate Moment	Mg=ps*Vs*Ys*+pc*Vc*Yc	523.42	KNm	**pc**	1600 kg/m3
6	Water moment	Mw=Pw*g(Vb*Yb*Ww*Hw*Lw*Yw)	794.22	KNm	**vc**	3.85 m3
7	Downstream moment	Md=(pg(H+h)^3*Ww)/182	8.608		**Yc**	1.075 m
8	Width of Spillway	Given	84	m		
9	No. of Fuse Gates can Install	N=W/3.225	26	No.		
0	Total Overtopping Discharge	Q=N x Each Fuse Gate Disharge	619.42	m3/sec		

3.7. 3D Design Model Simulation Of Fuse Gate:

A 3D Modulation of Fuse Gate Made Using Advanced tools and Softwares Utilizing Sketchup&V-ray for 3D simulation as shown in “Figure 9, 10”.

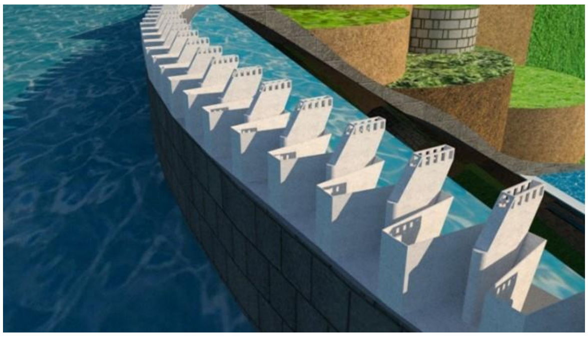

Figure 9: Side View of Fuse Gates 3D simulation

Figure 10: Top 3D view of Rawal Dam and Fuse Gate

IV. CONCLUSION

This study investigates the Application of Fuse Gate for the efficient flow control and River Management in Pakistan.And develop a fuse gate/rubber dam design to enhance the Storage Capacity of Rawal Dam and ensure the stability of the infrastructure for effective flow regulation at Rawal Dam. Enhancing the spillway discharge capacity aims to mitigate the risk of downstream flooding.

- The Resting Moment (RM) of Ram Dam are 2672193.095 KNm and Overturning Moment (OM) are 1136192.102 KNm Calculated Before the Installation of Fuse Gate. As RM>OM , therefore dam is stable enough to install fuse gate.

- After Installating Fuse Gates, As The Head of Water level Increases therefor the The Resting Moment (RM) of Ram Dam calculated as 2813754.848 KNm and Overturning Moment (OM) of 1208797.09 KNm calculated . Now also the RM>OM . therefore, The dam is Safe.

- Other safety Parameters like Ecentricity, Factor of safety against tension, overturning , and sliding are calculated and meet the safe limit above in results seperately for both above stability ensurance conditions.

- After Installation of Fuse Gate, the Storage capacity of reservoir increases from 15293 Acre-Feet to 28310 Acre – Feet. As per Hydrographic Survey Report of Rawal Dam (2019) the reservoir elevation level is at 1742 SPD (ft) which is sill level of existing Gates, while After Installation of Fuse Gate the New sill Level is at 1752 SPD (ft).

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