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MATHEMATICAL AND ANALYSIS MODEL OF SHAFT SPILLWAY.A REVIEW

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Abstract
Shaft spillways can also be referred a "morning glory" spillway . It's a hollow shaft or tower with a funnel at the top that is typically circular in shape. Situated in the reservoir close to the dam is the tower.Water pours over the edges of the reservoir and descends into the vertical shaft when the reservoir level rises above the top of the shaft spillway.At the base of the vertical shaft, it come on a tunnel. Usually, the tunnel passes beneath the dam, rerouting the water such that it joins the river downstream. The most significant disadvantage of these morning glory was the receiving hopper's "poor hydraulics" as a result of flow failure. In order to remove such disadvantage, a significant quantity of earthwork was required. The hazard of landslides and slope cutting resulted from the usage of water approaches to the receiving hoppers.

Keywords: Spillway, Discharge, Morning Glory,physical and numerical modelling.

1. Introduction

In 1923, the first shat spillway was constructed in England [1]. During the implementation of V-section waterworks, the process of diverting the river is carried out by means of diversion tunnels. According to multiple estimates, the expenses associated with river diversion projects might amount to around 30% of the total cost incurred in the development of a hydroelectric complex.Typically, upon the completion of the construction, the diversion tunnels were decommissioned. A suggestion was made to employ diversion tunnels as spillways in order to reduce construction expenses. In order to achieve this objective, vertical structures were constructed above the diversion tunnels to facilitate the discharge of flows. One significant drawback associated with these shaft spillways was the suboptimal hydraulic performance of the receiving hopper, primarily attributed to flow failure. In order to mitigate this drawback, a substantial quantity of earthwork needed to be executed. The implementation of water-based methods for transporting materials to the receiving hoppers resulted in the excavation of slopes and an increased risk of landslides. In order to address this limitation, the construction of the spillway shafts was initiated within the aquatic region of the reservoirs. The shaft spillways have emerged as a prominent building method and continue to be widely utilized.

The spillway is a hydraulic structure that serves as a critical safety mechanism for a dam [1]. The system effectively manages the flow of surplus water downstream. The spillway's design should possess adequate ability to effectively discharge floodwaters in excess of the reservoir's storage capacity. The implementation of a well-designed spillway serves to mitigate the possible hazards associated with dam failure and overtopping. The presence of a spillway is of utmost significance in ensuring the safety and integrity of dams. The complexity of the spillway design is attributed to the substantial flow rates it must accommodate, which in turn give rise to challenges related to cavitation and high flow kinetic energy. The placement of a spillway in relation to a dam can vary depending on several factors. It can be integrated inside the dam structure, located adjacent to the dam, or situated at a considerable distance from the dam. However, it is generally considered optimal to construct the spillway as a separate entity independent of the dam [2].

The spillway can be categorized into several types based on numerous criteria. These include purpose, such as emergency and auxiliary spillways; flow, such as regulated (gated) and uncontrolled spillways; and hydraulic characteristics, such as chute, ogee, tunnel, side channel, and siphon spillways. The selection and design of the type are influenced by various factors, including topography, hydrology, geology, the project's purpose, and the project's economic considerations (3).

The discharge coefficient (C) is a numerical parameter used to quantify the effectiveness of a spillway in facilitating the movement of floodwaters[4]. This important design parameter analyses the approach channel losses. The losses include entrance losses, transition losses, and losses brought on by the upstream channel's curvature. These losses must be incorporated into the overall head in order to ascertain the heights of the reservoir [5].

In recent years, Iraq has experienced notable variations in the inflow of water as a result of both severe climate shifts and the construction of dams within the Iraq Rivers basin. In the year 2019, there was a notable rise in precipitation levels within the river basin throughout the winter season. This resulted in an excess of water that surpassed the natural storage capacity. The water levels in Iraq's dams reached the designated release capacity of the spillways. The emergence of some problems with the operation and design of spillways and dams has been attributed as the cause. Subsequently, a decline in water levels occurred, resulting in a significant reduction in water quantities during the summer season and the ensuing two seasons of 2020 and 2021. This necessitated a reassessment of the management

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plans for this water resource system by the competent authorities. In order to analyze and mitigate these issues and enhance the operational efficacy of Iraq's water resources system, it is imperative to evaluate and experiment with various scenarios to gauge this efficiency, particularly with regard to the hydraulic infrastructure, including dams and spillways [7].Numerous investigations encompassing numerical modelling and simulations, and experimental studies, as well as analytic studies, have been undertaken to examine spillways.An attempt is made to give a compilation of the most important and current studies in that topic.

Nohani and Mousavi,(2009) examined the influence of the number and width of vortex breaker blades on the intensity of spiral vortices and the effectiveness of the discharge system in a spiral spillway. To do this, A physical model of a shaft spillway was built by the researchers, who also conducted several experimental studies. The results indicated that the discharge coefficient of the morning glory spillway experienced a 20 % increase by increasing The total number of blades and a 9% increase by increasing both the number and width of the blades [8]. The study conducted by Nohani (2014) attempted to determine the discharge coefficient of shaft spillways, specifically under the geometric conditions of the spillway crest. This was achieved through the utilization of a physical experimental model.The research investigation was conducted on shaft spillways of varying diameters, both with and without the addition of vortex breakers in the morning glory spillway crest . It is important to acknowledge that the assessment of the crest edge type conducted in this study. This study evaluated two types of crest edges, namely flat-edged and sharp -edged crests[9]. In a study conducted by Nohani and Gheisi (2014), an experimental investigation was performed to examine the impact of vortex breaker length on the discharge coefficient in a shaft spillway [10].

In a study conducted by Nohani (2010), an experimental investigation was conducted to investigate how a glory hole spillway's discharge coefficient is affected by the anti-vortex plate's tilt. [11]. In a study conducted by Nohani (2016)The present study investigates the quantitative evaluation of the impact of anti-vortex plates on the inflow pattern in vertical shaft spillways by the utilization of FLOW3D software.

The findings of the study revealed that the inclusion of a vortex breaker in a structure with dimensions of 10 × 8 × 5 has a substantial impact on the water flow at fixed water heights, as compared to a control condition. Furthermore, the discharge rate is observed to grow with the addition of more vortex breakers [11].In a study conducted by Nohani (2014), an experimental physical model was utilized to calculate the discharge coefficient for a morning glory spillway, specifically focusing on the spillway crest edge geometrical circumstances. This study examines the effects of different diameters of morning-glory spillways, both with / without anti-vortex elements at the top of the spillway. It is noteworthy that the investigation of the type of crest edge was extended in this study. This study examines two distinct types of spillway crest edges, namely sharp-edged and wide-edged crests [12]. The experimental investigation conducted by Petaccia and Fennochi (2015) examined the pressure variations and flow profile of the siphon spillways [13,14].

2.Selection of Spillway Types

The following actions should be taken into consideration when choosing a spillway:

-A spillway with specific dimensions is chosen.
- Reservoir flood routing for the design conditions determines the maximum lake elevation and maximum spillway discharge .
- Other dimensions are determined.
- The spillway and dam's costs are determined.
- The previous steps are carried out once more for:
- different combinations of reservoir capacity and dam heights utilising the reservoir's elevation storage relationship
- various types of spillways.
- The most cost-effective type of spillway and the optimum ratio of spillway capacity to dam height are selected[34].

3.Numerical and Experimental studies

In 2015, Ebrahim Nohani attempted to investigate the shaft Spillway's hydraulic performance through numerical modeling. The numerical modeling of the morning glory spillway was conducted using the Flow 3D software, in accordance with the standards set by (USBR). A numerical model was used to determine the hydraulic parameters of the flow, such as the pressure distribution, water level profile, and coefficient of discharge. After that, these parameters were contrasted with information obtained from the USBR and USACE models. The comparison of these parameters revealed a strong agreement and consistency between the results [15]. Amir Reza Razavi , Hassan Ahmadi(2017) , This study used a physical model to calibrate and validate flow using FLOW-3D. Next, by increasing the flow's suspended load, The discharge values that go through the spillway known as morning glory were established. In this regard, flow discharge values were examined for different heads over the spillway using suspended load (3000, 6000, 9000, and 12000 ppm). such that suspended load has a significant impact on deceased values [16]. L.L. Ebner, S.K. Askelson, E.A. Thompson and N.C. Cox(2016) The proposed alterations involve the elevation increase of two high head dams, measuring 56.4 m (185 ft) and 30.5 m, by 4.88 m. Additionally, there are plans to modify a service spillway to enhance its flood capacity, as well as construct a new labyrinth weir emergency spillway. In order to facilitate the design process for both spillwaysfor the Isabella Reservoir and associated outlet operations, a number of three-dimensional (3D) models for computational fluid dynamics (CFD) have been created. The design process for the emergency spillway has been optimized by the utilization of a composite modeling approach, which incorporates both physical and computational fluid dynamics (CFD) modeling techniques to analyze the performance of the labyrinth weir. A useful tool for assessing various spillway design possibilities is the computational fluid dynamics (CFD) model of the main, auxiliary, and forebay dams at Isabella Dam, as well as the service and emergency spillways, offer a valuable platform for evaluating different design options for the spillways. These models also aid in the production of rating curves and the validation of data received from physical models. The hydraulic conditions within and downstream of the spillway chute were assessed using the computational fluid dynamics (CFD) model outcomes. The computation of velocity, water surface height, and stream power was conducted in order to determine the necessary steps for protecting the chutes against erosive damage [17]. Enjilzadeh and Nohani (2016) conducted a study in which they utilized FLOW3D numerical models to perform a three-dimensional numerical simulation of the flow in the morning glory spillway of Alborz dam. The accuracy of the numerical model was assessed by comparing it to experimental data, and the relative error of the numerical model was used as a measure of its accuracy. The aim was made to determine the flow pattern and control conditions of shaft spillways in various modes by considering boundary conditions, inlet conditions, grid spacing of the flow field, and the project rating curve of morning glory spillways. Based on the outcomes of the numerical model, the relative error of the numerical modeling is determined to be 6.4% when estimating the discharge rate of the spillways. The numerical modelling error in calculating the depth parameter of the flow in the spillway crest is 7.6%, as observed in comparison with the corresponding experimental results [18]. In their study, Smyth and Smyth (2001) proposed a model to explain the formation of the morning glory cloud, which occurs due to the resonant flow of a two-layer fluid over the terrain represented by the mountains of Cape York Peninsula. In the scenario where the upper layer is significantly deep, the equations of motion can be simplified to a forced Benjamin-Ono equation. The modulation solution's predictions are then compared to observational data regarding the morning glory phenomenon. It is observed that there is a satisfactory agreement between the predicted and observed pressure jump caused by the lead wave of the morning glory. However, there is a lack of agreement regarding the speed and half-width of this lead wave [19].

In the present study, Parham et al. (2019) conducted a simulation of the flow via a sectoral morning glory spillway utilizing a three-dimensional numerical model. The present study aimed to analyze the key properties of flow in spillways of this particular type, with a subsequent proposal of a mathematical relation to determine the rate of water release. In order to accomplish this, the geometry of the spillway crest was analyzed by considering five sector angles. Additionally, the flow characteristics and drainage capacity of each sector angle were compared. A mathematical equation was presented to determine the discharge flow rate of sectoral morning glory spillways. The findings derived from the correlation reveal that the calculations conducted using the given relation exhibit a maximum inaccuracy of 7.77%, which is observed at a sector angle of 62 degrees. The mistake percentage serves as a validation of the dependability of the relationship [20].

Atheer S. A., Ammar H. K., and Assim M. L. (2021) employed the Ansys Fluent 2020 R1 software to develop a numerical model. This model was utilized to simulate the flow parameters and determine the cavitation damage values associated with the design of the Haditha dam under three different discharge scenarios: 4700, 7140, and 7900 m3/s. Furthermore, this study aims to investigate the impact of gate vibration caused by dynamic water loads. The volume of fluid (VOF) model and the Realisable k-ε turbulence model have been utilised to computationally simulate the dynamic interaction between the water and air phases. The numerical model was validated through a comparison with a physical model. The Haditha Dam spillway's physical model was constructed using iron material, adhering to a scale of 1:110. The hydraulic laboratory was utilized in the design and construction of the project, adhering to the modeling principle of hydraulic systems. The findings indicated a strong concurrence between the physical and numerical models, as well as the k-ε turbulence model, in effectively simulating the Haditha dam spillway. This approach proved to be cost-effective and required minimal time investment. Cavitation damage has the potential to occur in the section extending from the initiation point at the terminus of the arched spillway to the downstream reaches. It is worth noting that no damage to gate vibration has been observed under the influence of dynamic water load [21].

M. Cihan Aydin, Ercan Isik, and A. Emre Ulu (2020), This work examines the analysis of a spillway aerator installed on a roller-compacted concrete dam with a height of 100 m. The objective is to address the issue of cavitation damage on the spillway surface by employing a two-phase computational fluid dynamic model. Numerical analysis was conducted on prototype dimensions across a range of flow circumstances, including flow rates of 5223, 3500, 1750, and 1000 m3/s. The resulting findings were then compared to relevant experimental observations documented in the existing literature. The occurrence of cavitation on the surface has been observed based on numerical and experimental findings, which were supported by cavitation indices [22Liu, Guo, and Xia (2016) conducted tests and numerical simulations to investigate the flow behavior of the suggested intake and evaluate the performance of the vortex drop structure. The hydraulic properties of the outlet tunnel, including the flow pattern, distribution of air core, position of the annular hydraulic jump, pressure profiles, and water profiles, have been acquired and exhibit a strong agreement with the experimental data that was measured. The findings indicate that the flow surrounding the entrance can be categorized into two distinct regions: a whirling zone characterized by unrestricted flow in close proximity to the piers, and a submerged region characterized by flow that is partially or fully submerged at the piers. The relationship between the

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flow rate and the relative dimensionless weir head in the submerged section exhibits a roughly linear growth pattern. Additionally, the discharge coefficient remains relatively constant at approximately 0.223The rotating flow movement mechanism of self-regulating submerged vortex shafts and the energy dissipation of the unique vortex drop shaft spillway are comprehensively explained through a mix of experimental investigations and computational simulations. The analytical calculations regarding the velocity and depth of the liquid flow in the shaft sections demonstrate a significant correlation with the results obtained from numerical simulation [23]. F. ASAD et al. (2014) discussed the best shape for the morning glory spillway's entrance. The effect of several parameters like maximum discharge coefficient and lowest possibility of cavitation (cavitation index) are explored. In order to achieve this objective, the computational fluid dynamics (CFD) technique, namely the finite volume approach, is employed to solve the 3D Navier-Stokes equations governing the flow behavior for various inlet geometries. The free water surface is represented using a water-air two-phase flow model, and the equations governing this phenomenon are solved using the volume of fluid (VOF) method. The modeling of flow turbulence is achieved through the utilization of the "K-Є model". The experimental data were utilized to validate the models, wherein the discharge, velocity, pressure, and cavitation index for various inlet shapes were computed and subsequently compared. The morning-glory spillway intake is characterized by various equations, such as the WAGNER equation (Y=aX^3.88), the CREAGER equation (Y=aX^1.87), and the circular form, which are utilized to represent its funnel profile shapes. In each model, a graphic depicting the variation of head (h) vs discharge (Q) is constructed and the outcomes are subsequently compared [24]. Jiri Soucek, Ladislav Satrapa, Martin Kralik, and Miroslav Broucek (2021) examined the hydraulic conditions near the intake portion of high shaft spillways.The system is outfitted with pro-vortex vanes and is designed to examine and evaluate the latest advancements in the modeling of shaft spillways. Additionally, it assesses the comparative outcomes of the spillway's functionality in relation to its capacity and overall hydraulic conditions, both prior to and after to the complete removal or repair of the vanes [25]. Fattor and Bacchiega (2009) conducted a series of experiments pertaining to the Potrerillos dam located in Argentina. A more optimal position for the morning glory spillway was identified, offering improved hydraulic conditions in comparison to the existing spillway constructed within the dam. Furthermore, within the context of their research, they put up enhanced boundary conditions in the area of the spillway associated with morning glory. In this work, assessments of vortex breaker blades and their optimal quantity for enhancing the spillway drainage capacity of the dam. The model they provided also yielded favorable hydraulic conditions, resulting in a notable decrease in the necessary excavations surrounding the spillway [26]. In a study conducted by Savic et al. (2014) at Belgrade University in Serbia, the researchers investigated the discharge flow rate in several dams in Serbia. To conduct their research, they utilized a laboratory prototype, which incorporated a deflector positioned downstream of the morning glory spillway crest. This laboratory prototype was created based on the original model. An algorithm for the design of morning glory spillways with a deflector was ultimately introduced [27]. In their study, Fais et al. (2015) investigated the hydraulic characteristics of a novel parabolic knee joint, which was positioned at the terminus of the vertical shaft in the morning glory spillway. This investigation aimed to compare the hydraulic performance of the parabolic knee joint with that of the conventional 90-degree knee joint and the multi-center knee joint. The findings of the study indicate that the parabolic knee joint, developed by the researchers, has a positive impact on enhancing the discharge capacity of the morning glory spillway [28].The study conducted by Xianqi (2015) centered on the examination of flow profiles within morning glory spillways of expansive dams. This study focused on the examination of the geometric and hydraulic properties of a variety of big dams equipped with morning glory spillways. The primary objective was to analyze the maximum outflow rates of each dam, thereby treating them as individual case studies. Subsequently, a physical model was utilized to implement five distinct geometric and hydraulic designs [29]. The study conducted by Alfatlawi and Alshakli (2015) centered on the forecasting of the coefficient of discharge pertaining to a stepped morning glory spillway. For the purpose of this study, two shapes of spillways were examined experimentally: circular and square. Each geometric shape was subjected to experimental models involving 4,5,and 6 stages. The experimental findings were subsequently employed to forecast the coefficient of discharge through the utilization of Artificial Neural Network (ANN) and Multiple Nonlinear Regression (MNLR) methodologies. The findings indicate that the coefficient of discharge of the stepped morning glory spillway exhibited a reduction when the ratios of head to length and/or head to radius increased (Reference 30).In their study, Nohani (2015) utilized a numerical model to examine the hydraulic parameters of flow, including the coefficient of discharge, water level profile, and pressure distribution. These findings were then compared to data acquired from models developed by the US Army Corps of Engineers (USACE) and the United States Bureau of Reclamation (USBR). The findings indicate that while there is a satisfactory level of agreement between the results when comparing the parameters, the application of the numerical model to real samples is subject to some restrictions. These limitations include constraints related to the network's size and number, processing time, and the accurate representation of weather conditions [31In their study, Shemshi and Kabiri (2016) conducted an investigation on the phenomenon of whirling flow at vertical shaft spillways. They utilized an original geometric design known as the circular piano-key (CPK) inlet, and employed model experimentation as their research methodology. The findings of the study indicate that the magnitude of the whirling flow in the CPK spillway is significantly smaller compared to that observed in basic shaft spillways [32].at their study, Musavi-Jahromi et al. (2016) conducted a series of 170 tests on a physical model of a spillway at KWP. The experiments focused on varying the numbers and angles of vortex breakers to investigate their impact on the increase in the discharge coefficient rate. According to the findings of the conducted tests, it was determined that the optimal configuration for this particular feature is the installation of six vortex breakers on the spillway, each positioned at a 45-degree angle [33].

4. TYPES OF SHAFT SPILLWAYS

Based on hydraulic activity, shaft spillways are classified:

4.a. spillways have axial flow in the downstream tunnel or leg and the shaft .

It is possible to combine different flow condition combinations:

A. Both the tunnel and the shaft should be free flow.

B. There is pressure flow in the tunnel and free flow in the shaft.

C. There is free flow in the tunnel and pressure flow in the shaft.

D. Pressure flow occurs in the tunnel and in the shaft. [35]

4.b.spillways in the tunnel with axial flow and a vortex or swirling flow in the shaft.

China uses a lot of vortex drop shaft (VDS) spillways because of their many strong qualities, including high energy dissipation, steady flow regimes, and superior terrain adaptability. In addition, VDS spillways have the ability to move the energy dissipation and flood discharge task into the tunnel compared to traditional ski-jump energy dissipaters. This effectively prevents outlet atomization caused by the interaction between air boundary water and lessens the impact on the ecological environment. Shapai, China, Xiaowan, China, Jiayan, China, etc. are a few places where VDS spillways are currently in place. However, in other parts of the world, these kinds of structures are currently often used in urban drainage systems to transfer surface runoff or sewage from various levels. The analysis concentrated on the general structure and flow properties, which have numerous similarities despite the diverse application purposes. An inlet structure, a vertical structure, and an outflow structure are typical VDS design components. The three types of inlet structures are primarily divided into: (1) tangential inlet , (2) vortex slot inlet (3) spiral inlet . In order to maintain a stable air core and convert horizontal or sloping flow into a stable helicoidal flow, the intake structure must leave enough space for air to depart. [36].

4.c. spillways in the tunnel with whirling flow and axial flow in the shaft.

Morning glory spillways with high head applications that include axial flow within tunnels provide a risk of cavitation-induced damage, requiring the installation of an elaborate and costly energy dissipation system. To solve the aforementioned issues, shaft spillways with vortical water discharge—which is characterised by a swirling or spinning flow—were created in the former Soviet Union.. Along the inner perimeter of the tunnel, the flow revolves around the longitudinal axis. The incidence of cavitation is greatly reduced as a result of the impact of centrifugal forces and raised pressure on the tunnel's walls, and the interaction of friction with the boundary improves energy dissipation. While several modest spillways were built in Italy, the former USSR developed massive discharge applications, particularly for the dams of Medeo,Nurek , Katun, Rogun, etc. While several modest spillways were built in Italy, the former USSR developed massive discharge applications, particularly for the dams of Medeo,Nurek , A specially made spinning mechanism at the base is responsible for the tunnel's flow's spinning activity.

In general, there are two kinds of layouts: vertical and horizontal. The shaft in the vertical layout could feature a control gate in addition to being vertical or inclined. Without the use of a particular spinning device, the horizontal architecture achieves flow spinning through angular deflection of the flow in the horizontal plane. To achieve flow spinning in an inclined or vertical arrangement, a device known as a swirl chamber or swirling device is necessary.
[37].

4.d. Siphon-shaft spillways.

A hood that generates siphonic pressure is placed over a shaft spillway to form a siphon-shaft spillway. Because of their siphonic sub-atmospheric pressures, syphon spillways are employed to pass greater discharges at lower crest heads than free napped spillways. The benefits of syphon spillways are high sensitivity to changes in the water level upstream and high discharge per length of sill. (Houichi.et al2009)[38]. On the other hand, in order to prevent issues like body leakage and vibration, shaft spillways may be recommended, particularly in arch and embankment dams. The advantages of both shaft and syphon spillways are combined in the hybrid siphon-shaft spillway design. In siphon-shaft spillways, as opposed to shaft spillways, the same flow discharge can be conveyed with smaller sections since the syphon effect increases the velocities in the cross section. The reservoir's water level has less of an impact on the weir discharge than it does on free overflow spillways. It can function to its fullest potential with a modest crest head. Because the syphon head stops the free vortex, vortex effects are smaller than with free surface shaft weirs. Furthermore, the silt accumulation nearer the reservoir base might be absorbed by the inflow mouth. [39].

5. Mechanisms for ensuring pressurised flow in the morning glory spillway

In the event that the shaft spillway is not experiencing full flow, it is possible for hydro-pneumatic events to arise, leading to disruptions in the flow within the tunnel. Several locations are recommended to install specialized equipment that cause the water column inside the shaft to become stationary. The minimum height of this column should be such that air discharges and mass oscillations are effectively minimised. Some of these are :-

1- Special form of the bell-mouth entrance
2- chute blocks at the shaft's entry
3- syphon at the bottom of shaft
4- limited radius curvature
5- T-transition
6-.Nozzle
7- Diving flow in a stilling basin [35]

6. DESIGN OF SHAFT SPILLWAY

The spillway's discharge capacity is determined by the shaft's diameter. A spiral flow with a stable air core and maximum discharge capacity can be accomplished, according to the shaft spillway model, provided the shaft satisfies Fr, which is expressed as

$Fr = Q/(gD^5)^{1/2} \approx 1$

where Q is the spillway's maximum design discharge, g is the acceleration due to gravity, and D is the shaft's diameter Consequently, the drop shaft's diameter is selected. (Jain 1984) to be

$D = \sigma (Q^2 / g)^{1/5}$

where σ is the safety factor.. For a tangential inlet, Jain (1984) applied σ = 1, while Hager (1990) recommended σ = 1.25 for a cost-effective design. Dong (2011) suggested that for the approach channel, $\sigma = (1 + Fr)^{0.035}$, where Fr is the inlet channel's Froude number. A weir's discharge coefficient, Cd, is primarily determined by the number of submerged and spiral-flow-generating piers (n); the dimensionless relative head of the weir H/RL, where H is the designed maximum water head and RL is the annular weir's plain radius; the intersection angle θ between the piers and the weir; and the dimensionless pier height h/H, where h is the pier height above the weir's top. Additionally, the weir height P/H, pier length L/H, and pier width W/H (where P, L, and W are the weir height, pier lengths, and pier widths, respectively) have an impact. But even with a conventional morning glory weir, it can be difficult to measure the coefficient of discharge precisely.The shaft's discharge can be written as

$Q = Cd 2\pi RL (2g H^{3/2})^{1/2}$

It is simple to derive RL by converting the equation using the fraction $(H/RL)^{3/2}$ as follows:

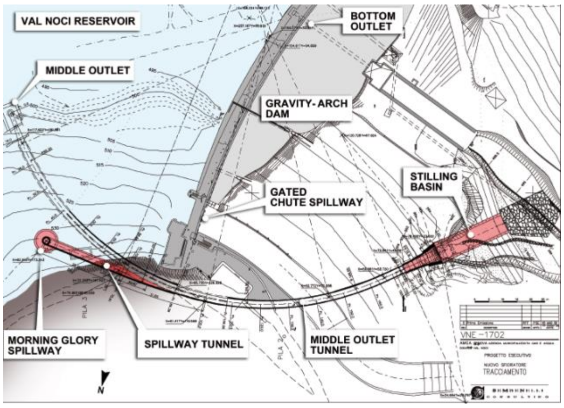
$RL = (1 Cd 2\sqrt{2}\, \pi (HRL)^{3/2}) 25 (Q \sqrt{g})$

where it is possible to derive the coefficient K as $K = 0.417 / Cd^{0.4} (H/RL)^{0.6}$.

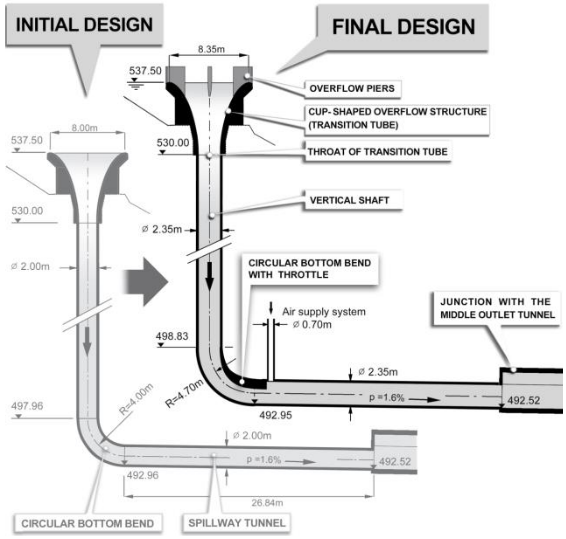
Eq. (4) shows that the shaft diameter D can be used to express the radius of the morning glory weir (RL).[40]

7. EXAMPLE OF SHAFT SPILLWAY

The Val Noci reservoir in Montoggio, Italy, is managed by Mediterranea delle Acque for the purpose of providing water to the city of Genoa . The reservoir at Val Noci is contained by a dam that stands at a height of 56 meters. This dam has the capacity to hold a useful storage volume of 3.3 million cubic meters. Three spillway structures are currently in place to facilitate the discharge of floods. These structures include a gated chute spillway, as well as a middle and a bottom outflow, as depicted in Figure1. According to a recent assessment of the flood hydrograph, it has been determined that the current discharge capacity is insufficient to accommodate the observed flood levels. In order to address the aforementioned scarcity, Mediterranea delle Acque intends to construct a supplementary shaft spillway, as depicted in figure (2). The proposed design will utilize the pre-existing middle outlet tunnel in order to achieve cost savings.



Figure(1) A plan image of the Val Noci dam showing the structures that make up its spillways, Morning Glory Spillway projections and the intermediate outlet tunnel



Figure(2) Layout of shift spillway in its initial and final design

It was necessary to validate the operation of the shaft spillwa,. In the physical model, the project design that the client submitted was evaluated at first, which had a scale factor of25 .The carried out model tests on the initially developed design revealed that when the vertical shaft's free flow changed to pressurised flow, the lowest pressures experienced a decrease below the vapor pressure when scaled up. This led to a phase change from water to vapor, specifically the separation of the water column. At the prototype's site, this phenomenon could cause significant vibrations, resulting in structural damage and a reduction in shaft spillway capacity . VAW implemented two modifications to improve the initial concept of the shaft spillway: enlarging the vertical shaft and incorporating a throttled bottom bend. In addition, the VAW implemented the installation of overflow piers at the peak of the morning glory structure in order to promote radial flow and prevent the formation of air-entraining vortices. As a result, the discharge capacity of 75.1 m3/s is effectively maintained, while also mitigating excessive pressure oscillations within the vertical shaft. An air supply system is strategically positioned downstream of the throttle mechanism to facilitate unobstructed aeration within the spillway tunnel [41].

8.Conclusion :

A morning glory is when water from a reservoir enters a vertical shaft, travels down a horizontal tunnel, and eventually discharges into a river down stream Small shafts can be built entirely of concrete or metal. If it is difficult to build a side spillway chute or crest spillway in a small valley with steep slopes, then a shaft spillway is a suitable form of protective structure at lower design flows. If it is a part of a larger construction or if the diversion tunnel serves as the spillway outlet, its advantages become even more apparent. There is an intake component in the shaft spillway, knee pipe, exit tunnel, shaft, and transition section Traditionally, the intake element was constructed with a wide crest, but it now typically has a circular plan with a hydraulically fitting crest. On the crest and in the intake section, baffle ribs are frequently built to deflect, reducing the creation of random whirlpools and stabilising the flow. A spiral flow regime is produced in the shaft and the funnel-shaped transition section by the curved baffle ribs. The distribution of pressure across the spillway casing is more uniform. In the upper portion of the spillway, the water jet is forced towards it to prevent under pressures that could result in cavitation phenomena and vibrations. The flooding of the shaft spillway is a complicated hydraulic process. With increasing discharges, the length of the flooded shaft section, through which the free fall of water through the shaft is facilitated by the transition phenomena, rapidly increases. The spillway's intake and transition section need to be designed to prevent flooding before the shaft. Every hydraulic phenomenon that arises during the two-phase flow must be included in the hydraulic solution.

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