2528-9705

Örgütsel Davranış Araştırmaları Dergisi

Journal Of Organizational Behavior Research

Cilt / Vol.: 7, Sayı / Is.: S, Yıl/Year: 2022, Kod/ID: 22S0-884

A numerical and Experimental Study of Permeability Coefficient in Lower Discharge Ducts

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ABSTRACT

Drainers are a group of devices that move water from a dam lake to a downstream disposal point. This research aimed to determine the numerical and laboratory permeability coefficients in the lower discharge ducts. The physical model of ducts and valves created in the Soil Conservation and Watershed Management Research Center laboratory was utilized in this study and the relevant testing. The numerical discharge model was simulated using Flow 3D software to compare experimental and numerical results and prior results in this work. The findings revealed that variations in the permeability coefficient up to 50% opening of the service valve did not follow a predictable pattern but increased with increasing openness from 50% onwards. The flow rate via the duct was studied, and it was discovered that raising the opening of the valves increased the flow rate, which logically demonstrates high performance and is compatible with previous models. Compared to experimental data, the quantity of flow rate received from the software has a pretty acceptable accuracy, but the flow rate obtained from the program is always higher than the flow rate recorded in the laboratory. The proportion of mistakes varies between 2 and 16 percent for a single valve and 3 to 15 percent for combined operation, with most errors occurring at the lowest opening, i.e., 30 percent.

Keywords: *Dam Lake, lower discharge, permeability coefficient, flow rate*

INTRODUCTION

Lower dischargers are employed when the water depth in the dam reservoir is high for downstream water consumption and to drain the dam in emergencies, and in certain cases, to drain the accumulated sediments in the dam reservoir (Hosseini and Abrishami 2008). Drainers are commonly used to redirect water during construction and, if they are reliable, may be utilized to assist with drainage planning. These structures are modest in arched or gravity dams, but they are much larger in earthen dams. A big discharge is frequently separated into two pressurized portions (controlled by a high-head valve) and an exit tunnel to shorten the length of the pressurized section (which transmits subcritical current to the atmosphere).

The two-phase air flow is conveyed at high speed in the lower dischargers. A significant reduction in downstream pressure values occurs due to the separation of the current and its quick conversion from the pressurized to the free condition. One of the most critical difficulties with valves is how to reduce the negative pressures caused downstream of the valve. Negative pressures will eventually cause harm to the structure's foundation and the valve itself. Cavitation is a particularly uncomfortable hydrodynamic phenomenon caused by the negative pressure exerted downstream of the valve. This is normally controlled by injecting air through an aeration tube.

Speed is an important characteristic that, in addition to identifying the downstream flow pattern, is critical in understanding the cause of cavitation and vibration. The Reynolds number of the flow is frequently greater than 10^5, indicating a turbulent flow due to the high velocity of the flow in the duct and beneath the valve. According to research, if the discharge tunnel's flow velocity exceeds 10 meters per second, the flow should be aerated to avoid cavitation (Khosrojerdi and Kavianpour, 2001). The flow in the lower discharge duct is extremely sensitive to the duct's geometrical features, and even little changes can alter the findings. The researchers developed a correlation to assess the pipeline network's divergence conversion profile. Researchers compared the results of the sliding valve model of the Maroon Dam's lower drainage tunnel to the aerodynamic model. The results are quite similar to the aerodynamic model's test results. The effect of various factors such as increasing the width and height of the duct section downstream of the valve, the presence of a step immediately after the valve to open and close the valve, and the effect of opening and closing the air shaft installed downstream of the valve on the amount of valve permeability was also examined in the form of various experiments by testing the dam discharge valve.

Safavi (2007) investigated the needed airflow after the valve in the dam's lower discharge tunnels. In his tests, he looked at the process of flow ventilation and the impact of variables like air duct diameter, tunnel length, tunnel filling percentage, and flow rate on the volume of air entering the tunnel and negative pressure behind the valve. By investigating the quantity of aeration on models of evacuators such as Siazakh, Gotvand, and others, Kavianpour et al. (2010) revealed experimental correlations for the number and diameter of aerated tunnels.

Because of the complexity and three-dimensionality of the flow pattern, primarily due to the complexity of the flow path geometry in the areas around the valve, accurate results from theoretical modeling are not practical for many effects. They will not provide the designer and manufacturer with a definite assurance of vibration and cavitation-free operation. As a result, many large dams must test the hydraulic model for valves due to the high cost of dam construction and accompanying infrastructure and damages and human and financial losses caused by prospective valve failure. The permeability coefficient in the lower discharge ducts is examined numerically and experimentally in this work.

Method

Design and construction of experimental models

The descent concept may be used to create a pressurized duct model if the Reynolds number of the flow is more than 105. As a result, using the design flow given by the design consultant, the Reynolds number of the flow was computed and observed as follows: the Reynolds number was in this range.

$$L_m = \frac{L_P}{\lambda} \qquad \text{Eq. 1}$$

$$P_m = \frac{P_P}{\lambda} \qquad \text{Eq. 2}$$

$$V_m = \frac{V_P}{\lambda^{0.5}} \qquad \text{Eq. 3}$$

$$Q_m = \frac{Q_P}{\lambda^{2.5}} \qquad \text{Eq. 4}$$

$$T_m = \frac{T_P}{\lambda^{0.5}} \qquad \text{Eq. 5}$$

where L, P, Q, T, and V λ represent the length, pressure, flow rate, time, velocity, and geometric scale, respectively.

Simultaneous Reynolds and Froude number similarity necessitate the creation of a model the size of the actual sample. As a result of the difficulties of this problem, engineering operations normally make models based on the landing number. Reynolds similarity can also be neglected for high Reynolds numbers (greater than 10^5) (Novak, 1981), and only the Froude number can be employed as a criteria of similarity.

$$R_e = \frac{V_p y_p}{\nu} = \frac{30.36\times 2}{10^{-6}} = 61\times 10^6$$

It should be mentioned that the above requirement is true to decrease the prototype up to 72 times, according to the following calculations:

$$Q_{\max} = 85 m^3/s \Rightarrow V_p = 30.36 m/s$$

$$\mathrm{Re}_p = \frac{V_p y_p}{\upsilon} = \frac{33.36\times 2}{10^{-6}} = 6.1\times 10^7$$

$$\mathrm{Re}_m = 10^5$$

$$\lambda_r^{1.5} = \frac{\mathrm{Re}_m}{\mathrm{Re}_p} = \frac{10^5}{6.1\times 10^7} = \frac{1}{610} \Rightarrow \lambda_r = \frac{1}{72} \langle \frac{1}{15}$$

In the presented equations mentioned above, the signs used are:

Rep Prototype Reynolds number (actual sample)

yp The height of the duct at the location of the service valve

Vp flow rate in the stream immediately after the service valve.

As a result, the chosen model 1:15 is bigger than the minimum permissible scale, indicating adequate.

Experimental model components

Model of Normashir dam's deep drainage duct, including repair valve, metal cover with rectangular cross-section, duct inlet, valve groove, middle duct, emergency valve, emergency valve chamber, its grooves, service valve, ventilation between two valves, and also at the bottom of the service gate that is made of the transparent sheet (Plexiglas) and in metal parts with full details according to the drawings provided by the design consulting engineer, with a scale of 1:50. The tank for the head A cylindrical tank with a height of roughly 18 meters has been employed to supply the requisite water height and flow, fed by two pumps with 100 liters per second. Figure 1 depicts the reservoir, and energy-retaining grid plates are utilized to moderate the flow and avoid water turbulence entering the reservoir (Hosseini et al., 2010).

Figure 1. A view of the head supply tank (Hosseini et al. 2010)

Piezometers have been fitted at important spots to correctly examine the flow pattern, sags owing to the design and jet outflow of the valve, investigate the flow between the two valves, and research the effect and quantity of aeration. 13 piezometers are mounted on the valve to measure pressures. These piezometers are coupled to firmly connected hoses and steered to the outside through open areas inside the valve, where the pressure of the above locations is removed by connecting to vertical manometers.

At the drain pipe's outflow, there is a relaxing pool. The pond's floor level is 1345.5 meters. The relaxation pool's length on the axis and at the upper level is 30 meters, and its width is 20 meters. The pool has a circular floor with a radius of 32.05 meters, and the inner slope of the pool's walls is horizontal to four vertical. As a result, the pool wall to floor level height equals 16 meters. The relaxation pool's last section has a shared construction and a deep discharge exit. This section of the pond that finishes in the river has a width of 25 meters.

The tests included pressure measurements in various areas of ducts and valves and flow rate and air velocity measurements in aerators; in this case, all three levels of the dam reservoir were tested. The tests were carried out at a maximum water load of 670 cm, a normal water load of 636 cm, and a minimum water load of 327 cm. After recording the water level in the model tank, flow and pressure measurements, and air velocities for six service valve openings (10%, 20%, 40%, 50%, 60%, and 80%), as well as a fixed face emergency valve, were taken. Then, for optimal performance, trials were conducted on the head.

A point gage positioned adjacent to the canal was used to measure the overflow. The observed error rate was predicted to be less than 2.6 percent due to variations in water level on the overflow and fluctuations in the water level profile. Inlet pumps and a tank drain control the effective water level in the tank. All of the tests were done with three different tank heads.

By reading the central wire of the camera with the aiming point on a particular millimeter-calibrated ruler, the measurement precision is equal to 50.5 mm in the model (6 mm in the real sample). As a result, the level of various portions of the model is represented in two decimal places. A sharp rectangular overflow drives the flow in the model. Before the flow reaches the measuring point, three factors influence flow measurement error: channel construction error and sharp edge overflow and installation, bar's ash reading error (water blade height reading on the overflow), and model leakage error. A rod scale with an accuracy of ±1 mm is employed in the model to read the height of the water blade on the overflow.

Numerical model

The Flow-3D business code was used to solve the basic equations of fluidity and the equations of continuity and momentum in a three-dimensional way in this study. First, we create the physical model in SolidWorks software, import it into the program (Figure 2), and then mesh the model.

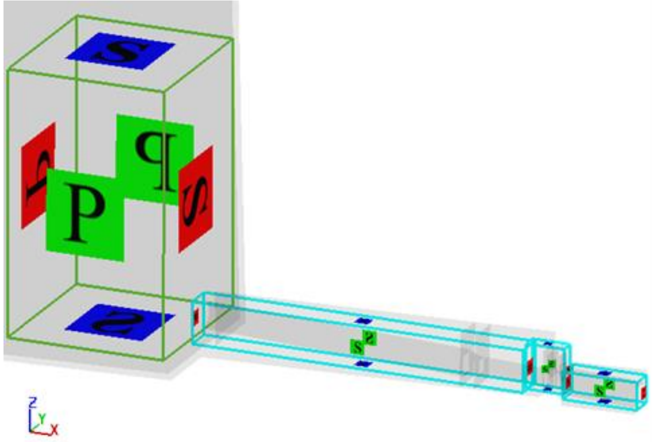

Figure 2. Showing the number and location of lattice blocks and their boundary conditions

Figure (3) depicts the water-filled sections of the model (Azimian, 1998).

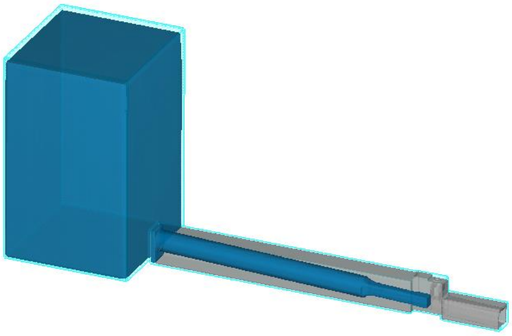

Figure 3. The initial location of the fluid before starting the analysis

Findings

1. The results of the experiments

1-1- Water permeability coefficient and capacity

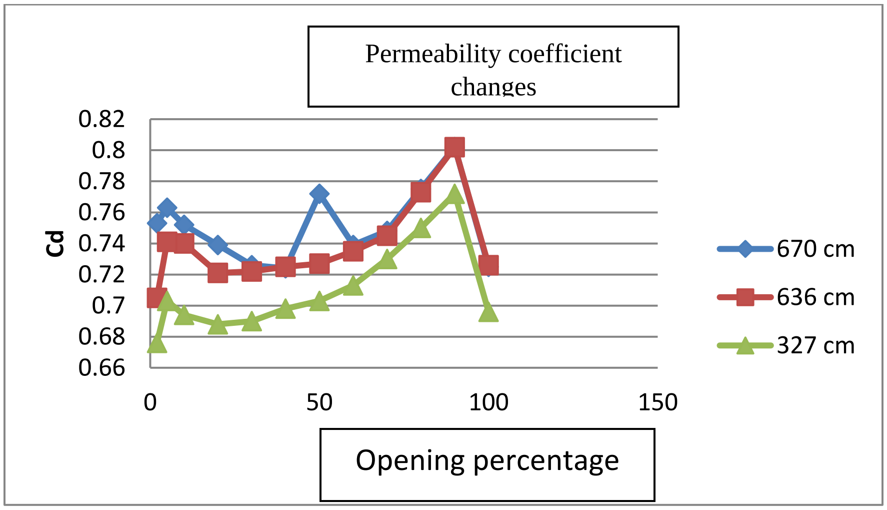

Figure 4. Changes in permeability coefficient in different heads

The variations in the permeability coefficient in the joint operating mode at the maximum head are shown in Figure (5).

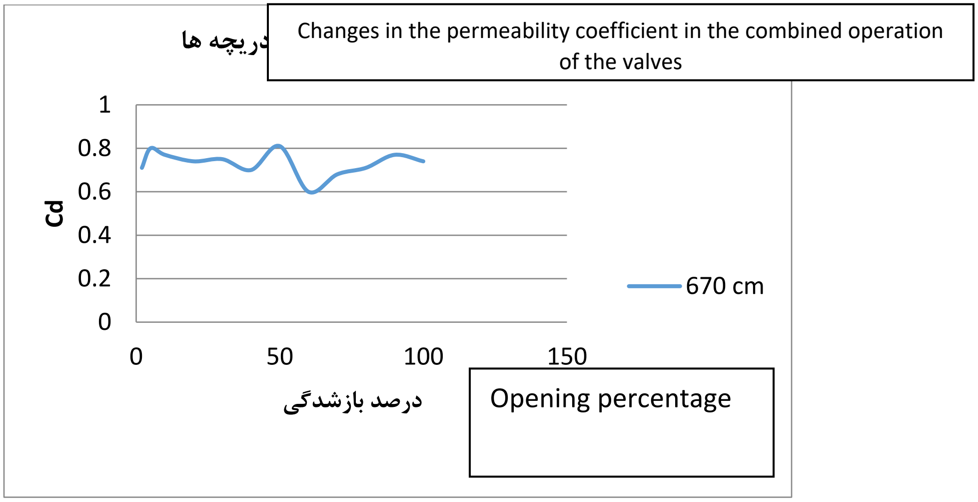

Figure 5. Changes in the permeability coefficient of the corresponding head

As indicated in the diagram, variations in the permeability coefficient did not follow a consistent pattern up to 50% opening of the service valve, but after that, it rose with increasing opening, which is greater for higher heads. The non-compliance of a pattern's permeability coefficient can be attributed to its reliance on many factors.

Figures (6) and (7) demonstrate how the flow rate through the duct changes in two modes of operation: single-valve service and combined operation. Examining flow fluctuations via the duct reveals that as the valve opening is increased, the flow rate increases, indicating high performance and consistency with previous models. The duct has a maximum throughput capacity of 90 percent openness and a head of 670 cm, which equates to 97.63 liters per second.

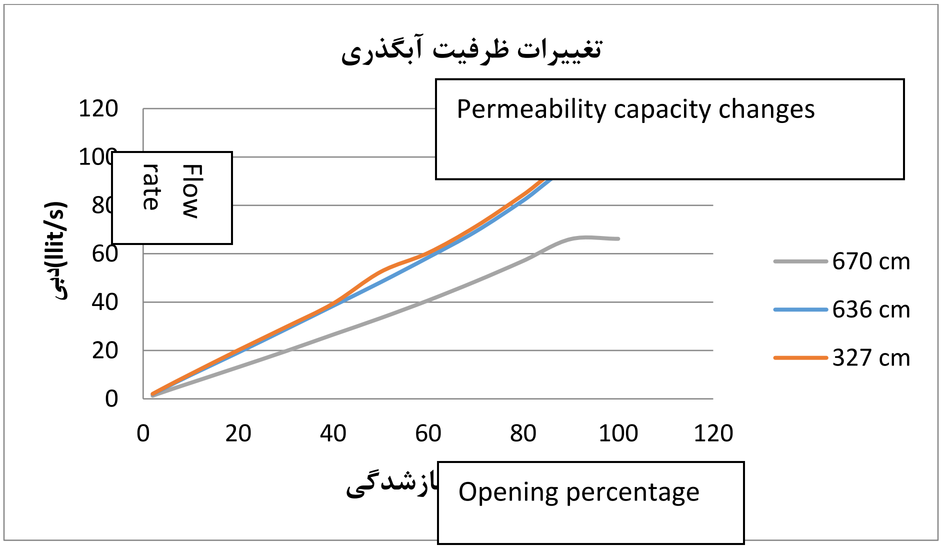

Figure 6. Changes in the amount of permeability in different heads

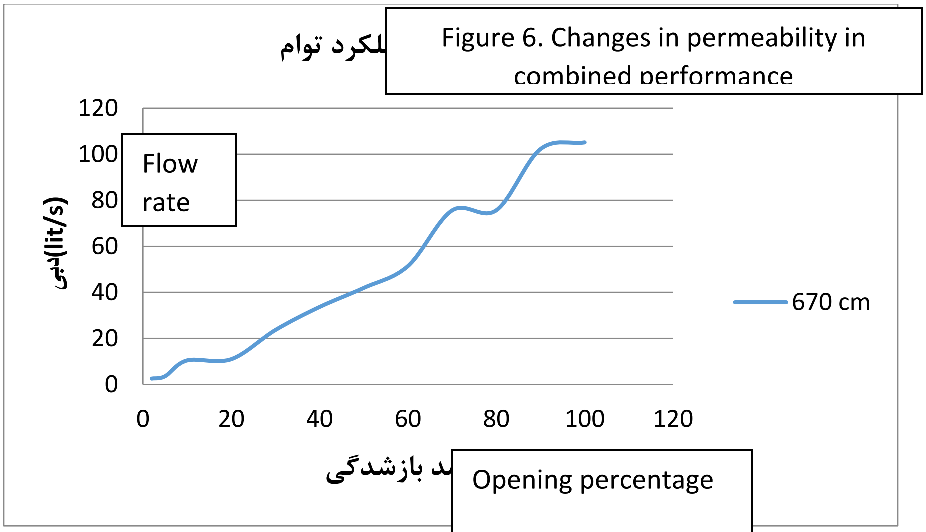

Figure 7. Changes in the amount of permeability in the relevant head

The variations in permeability capacity are linear with an appropriate approximation, as shown in the graphs, and rise with the increase in reservoir head.

2. Comparing the experimental and numerical results

2.1. Single valve operation mode

Table 1. Comparing the permeability coefficient between experimental and numerical results

Opening percentage	Experimental	Numerical	Error (mm)
80	0.78	0.8	2.56
60	0.76	0.78	2.63
30	0.73	0.74	1.36

2.2. Combined operation mode

Table 2. Comparing the permeability coefficient between experimental and numerical results

Emergency	Service	Experimental	Numerical	Error (mm)
78	80	0.71	0.8	12.68
57	60	0.6	0.69	15
29	30	0.75	0.86	14.66

3.2. Permeability capacity

When the results are compared, it can be observed that the flow rate acquired from the software has a pretty acceptable accuracy when compared to the laboratory data, although the flow rate produced from the program is always greater than the flow rate recorded in the laboratory. The proportion of mistakes varies between 2 and 16 percent for a single valve and 3 to 15 percent for combined operation, with most errors occurring at the lowest opening, i.e., 30 percent. The powder flow at low apertures produces additional inaccuracies in the software results, resulting in this error.

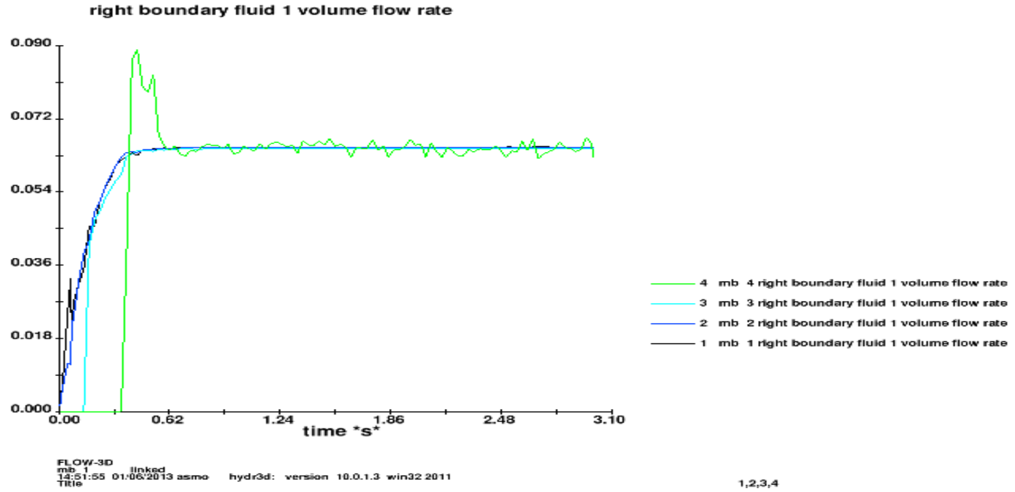

Figure 8. Software output: The amount of flow at 60% opening in the head is 670 cm

Conclusion

The results revealed that variations in the permeability coefficient did not follow a predictable pattern up to 50% opening of the service valve but that it rose with increasing opening, which was greater for higher heads. The non-compliance of a pattern's permeability coefficient can be attributed to its reliance on many factors. Examining flow rate variations via the duct reveals that as the valve opening is increased, the flow rate increases, indicating high performance and consistency with previous models. The duct has a maximum throughput capacity of 90 percent openness and a head of 670 cm, which equates to 97.63 liters per second. Compared to laboratory data, the quantity of flow rate received from the software has a pretty acceptable accuracy, but the flow rate obtained from the program is always higher than the flow rate recorded in the laboratory. The proportion of errors varies between 2 and 16 percent for a single valve and 3 to 15 percent for combined operation, with most errors occurring at the lowest opening, i.e., 30 percent.

Acknowledgment: None

Conflict of Interest: None

Funding: None

Ethical statements: None

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