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EFFECT OF DRAINAGE GALLERY DIMENSIONS ON THE UPLIFT FORCE OF A GRAVITY DAM

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ABSTRACT: Uplift pressure on the floor of the gravity dam affects the stability of the dam. Therefore minimizing the uplift pressure force can be achieved by constructing a drainage gallery. In the present work, three parameters of the drainage gallery are studied experimentally on a sand model of gravity dam to determine their effect on the total uplift force acting on the floor of the dam. These parameters are the diameter of the drainage gallery (d), spacing of the drainage gallery in the longitudinal direction of the dam (L), and the penetration depth (h). It is found that, the penetration depth of the drainage gallery is more effective in reducing the uplift force than the other two parameters. The average values of reduction in the uplift force attributed to the change of d, L, and h accounted to about 11 %, 25 %, and 40 % respectively.

INTRODUCTION

When drainage galleries are constructed at the floor of a gravity dam, the uplift pressure force is modified in accordance with the diameter, spacing, and penetration depth of the galleries. The purpose of this paper is to study the effect of these parameters on the total uplift pressure force acting on the floor of the dam.

A group of experiments were performed on a sand model by Abd El-Razek and Abo Elela (2001) to determine the optimum location of the drainage gallery underneath the gravity dam. This location was denoted by the position of the maximum reduction in uplift force acting on the dam floor. The optimum position of the drainage gallery in this case was found in the middle of the dam floor ($b/B = 0.5$). These experiments were performed on a gravity dam-sand model for constant diameter (d), spacing (L), and penetration depth of the drainage gallery (h).

The Bureau of Reclamations (1976) assumed that the uplift pressure varies linearly from headwater pressure at the upstream face of the dam to tailwater pressure at the downstream face. Also, the Bureau assumed that when drains are present, the uplift pressure at the dam foundation interface depend on the location, depth, and spacing of drains as well as on joints, shears, and other geologic structures in the foundation rock. The uplift pressure at the drain position is equal to the tailwater pressure plus one-third of the difference between headwater and tailwater pressures.

The Federal Energy Regulatory Commission (1991) did not recommend the effective characteristics but recommended that these should be determined through an evaluation of the character of the foundation and the effectiveness of the proposed drainage system.

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An analytical solution was presented by Amadei et al. (1989) in a dimensionless form and was used to show that drains are effective in reducing uplift pressures in dams. Effect of drainage gallery elevation, entrance head, and drain radius on uplift was also presented.

Amadei et al. (1989) also studied the effect of head losses in the drain pipe on crack uplift and drain effectiveness. They showed that, drainage wells are effective in reducing crack-induced uplift pressure, and found that, their effectiveness seems to be only significant for drains of small diameter. This reduction seems to be important only for drains with diameter less than 4 inches (101.6 mm) and for smooth cracks with large apertures.

Chawla et al. (1990) showed that when drains are constructed the internal pressure within the dam should be modified in accordance with the size, location, and spacing of the drains. The internal pressure distribution through the foundation is dependent on size, depth, location, spacing of the drains, rock porosity, jointing, faulting, and to some extent the grout curtain.

A specific analytical solution for flow through a horizontal crack of finite length drained by a series of vertical drains was presented by Goodmen et al. (1983). Their results showed that drain holes are effective in substantially reducing uplift pressure in a crack and have the greatest influence when located between approximately one half and one fifth of the length of the crack from its upstream end.

Grishin (1982) showed that drainage under a dam can be in the form of either a line of holes (drainage curtain) or galleries or cavities in the base of the dam commucating with tailwater through a discharge device in the form of pipe, gallery, drain filled with large grain material. It was shown that drain holes of diameter not less than 20 – 25 cm and spaced at 2 – 5 m in a row can be drilled downstream from the grout curtain. The depth of the drain holes depends on the type of foundation, and for a relatively uniform jointing the depth varies from 0.5 to 0.7 depth of the grout curtain.

Moffat et al. (1984) explained that the foundation uplift relief is affected by a line of drainage holes close downstream of the grout curtain in gravity dam. The holes are generally about 75 - 100 mm in diameter spaced at 3 - 5 m between centers, and are drilled from the inspection gallery. The relief drain efficiency is a function of drain geometry, i.e. diameter, spacing, and distance to the upstream face.

In the present work, the effect of diameter, spacing, and penetration depth of the drainage gallery to the magnitude of the uplift force acting on the floor of the gravity dam is studied using laboratory model tests.

EXPERIMENTAL SETUP

The Gravity Dam-Sand Model

The gravity dam-sand physical model shown in Figure 1 is designed by the authors to study the effect of diameter (d), spacing (L), and penetration depth (h) of the drainage gallery on the uplift pressure underneath the gravity dam. The drainage gallery is located at the optimum position beneath the dam floor ($b/B = 0.5$).

The dam model is represented by three perspex plates, two vertical plates represent the upstream and downstream faces of the dam. The third plate is connected with the vertical plate in horizontal position and represents the floor of the dam. The floor of the dam model contains one vertical perforated tube covered with the synthetic material which serves as a drainage gallery. The vertical tube is located at the middle of the floor. It incorporates a vertical copper bar with end screw end that controls the water entering the gallery. Eight piezometers that are positioned along the floor are used to monitor the uplift pressure distribution. Constant head of water at the upstream and downstream faces of the model can be monitored by using an overflow tube.

Procedure of Experiments

To study the effect of penetration depth of the drainage gallery (h) on the uplift pressure underneath the gravity dam, the following procedure is carried out:

1. For a constant diameter (d), spacing (L) and penetration depth (h) of the drainage gallery, and a constant water head at upstream face (H_1) and at downstream face (H_2) the model, the uplift pressure acting on the floor of the dam model is measured using the piezometers.
2. The water head at upstream face of the model (H_1) is changed four times and step No. 1 is repeated.
3. Four different values of penetration depth (h) of the drainage gallery are tested in the experiment and steps No. 1 and 2 are repeated for each penetration depth.

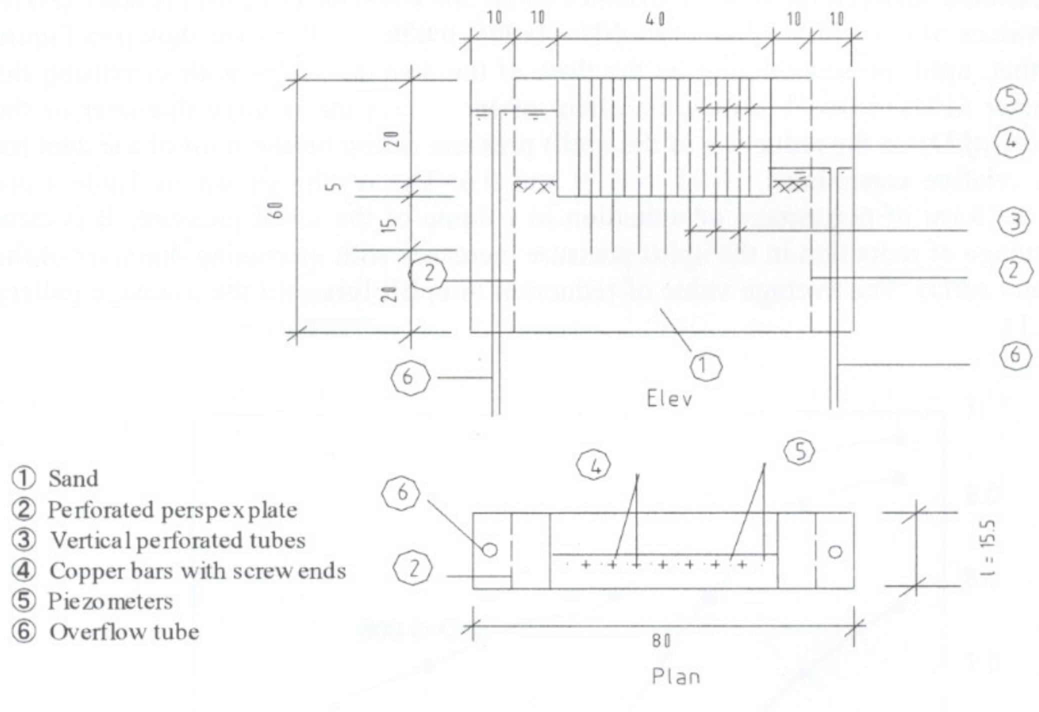

Fig. 1 Experimental set-up (Dimensions in cm)

To study the effect of the drainage gallery diameter (d) on the uplift pressure underneath the gravity dam, the following procedure is carried out:

1. For a constant diameter (d), spacing (L) and penetration depth (h) of the drainage gallery, and a constant water head at the upstream face (H_1) and downstream face (H_2) of the model, the uplift pressure acting on the floor of the dam model is measured using the piezometers.
2. The water head at the upstream face of the model (H_1) is changed four times and step No. 1 is repeated.

3. Four different values of diameter (d) of the drainage gallery are tested in the experiment and steps No. 1 and 2 are repeated for each diameter.

To study the effect of the drainage gallery spacing (L) on the uplift pressure underneath the gravity dam, the following procedure is carried out:

1. For a constant diameter (d), spacing (L) and penetration depth (h) of the drainage gallery, and a constant water head at the upstream face (H_1) and downstream face of the model (H_2), the uplift pressure acting on the floor of the dam model is measured using the piezometers.

2. The water head upstream the model (H_1) is changed four times and step No. 1 is repeated.

3. Four different values of spacing (L) of the drainage gallery are tested in the experiment and steps No. 1 and 2 are repeated for each penetration depth.

EXPERIMENTAL RESULTS

Effect of the drainage gallery diameter (d)

· The relationships between the relative distance (b/B) and the relative uplift pressure (P/H_1) for different values of the relative diameter (d/D = 0.005, 0.026 & 0.035) are shown in Figure 2. It is clear that, uplift pressure acting on the floor of the dam decreases with increasing the relative diameter (d/D). Table 1 shows the effect of increasing the relative diameter of the drainage gallery (d/D) on the reduction of the uplift pressure acting on the floor of the dam for values of the relative water head, H_2/H_1 = 0.39 and 0.6. The results shown in Table 1 are presented in the form of percentage of reduction in volume of the uplift pressure. It is clear that the percentage of reduction in the uplift pressure increases with increasing diameter of the drainage gallery (d/D). The average value of reduction in uplift force for the drainage gallery diameter is 0.11.

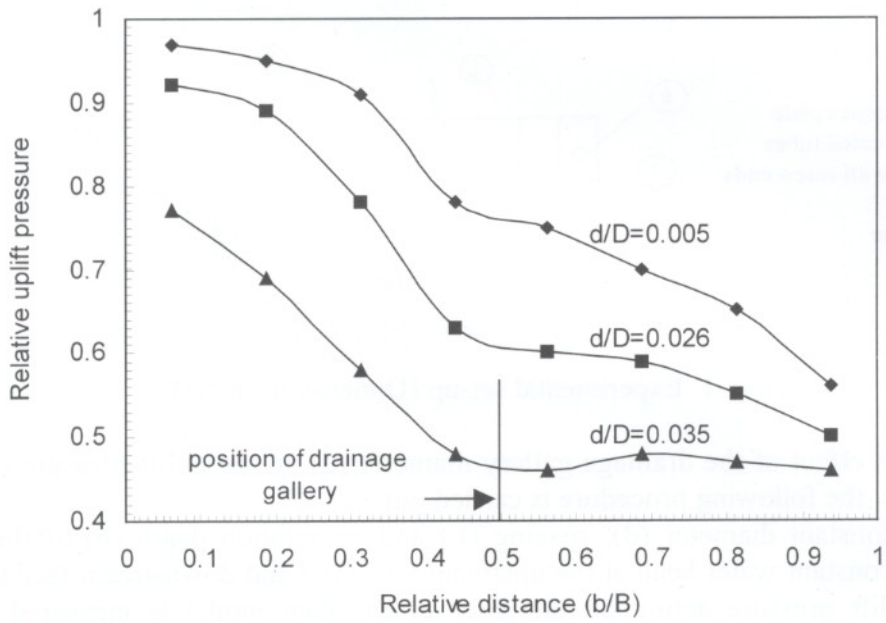

Fig. 2 Relative uplift pressure (P/H_1) versus relative distance (b/B) for different values of the relative diameter (d/D) (H_2/H_1 = 0.39, h/D = 0.0 & L/D = 0.39)

Table 1 Percentage of average reduction in volume of uplift pressures, for $h/D = 0.0$ and $L/D = 0.39$

d/D	H_2/H_1 0.39	0.6	Average percentage (%)
	Percentage of reduction in volume of uplift pressure due to construction of drainage gallery beneath the gravity dam (%)		
0.005	3	3	3
0.016	7	7	7
0.026	13	11	12
0.035	22	19	21

Effect of the drainage gallery spacing (L)

For constant values of the relative penetration depth, $h/D = 0.375$ and relative diameter, $d/D = 0.016$, the relation between the relative spacing of the drainage gallery in the longitudinal direction (L/D) and the average percentage of reduction in uplift pressure for different values of the relative water heads ($H_2/H_1 = 0.39$, 0.47, 0.53 and 0.6) is obtained experimentally and summarized in Table 2. For the relative spacing (L/D) range from 0.14 to 0.24, the corresponding average percentage reduction in the uplift pressure decreases from 34 % to 23 % was observed. With increasing relative spacing (L/D) from 0.24 to 0.39, the average percentage reduction in the uplift pressure is constant and equals 23 %. This means that the effect of the drainage gallery spacing on reduction of the uplift pressure appears at relative spacing (L/D) less than 0.24. The relationships between the relative distance (b/B) and relative uplift pressure (P/H_1) for different values of the relative spacing ($L/D = 0.14$, 0.24 & 0.29) are shown in Figure 3 indicating a decrease in uplift pressure acting on the floor of the dam with decreasing the relative spacing (L/D).

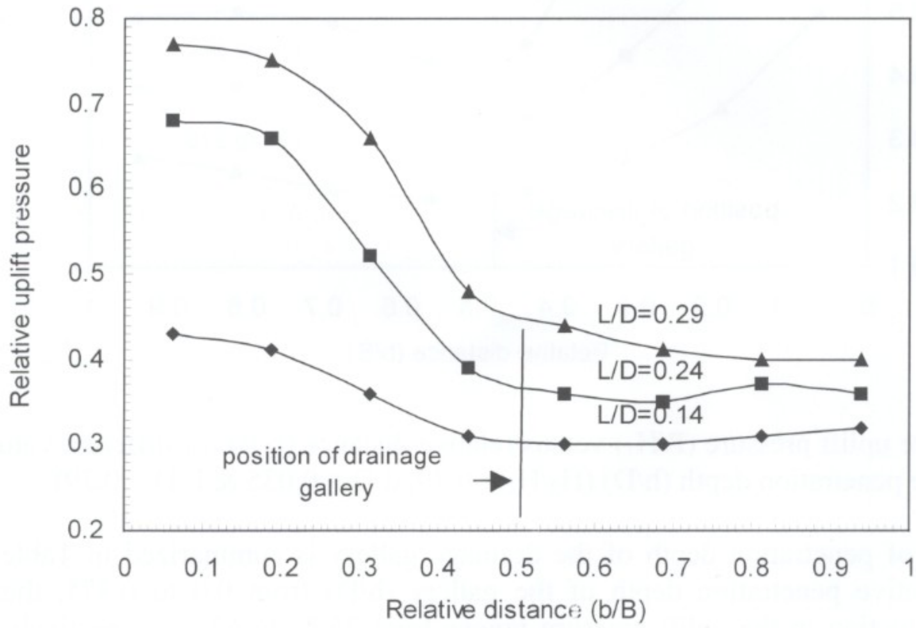

Fig. 3 Relative uplift pressure (P/H_1) versus relative distance (b/B) for different values of the relative spacing (L/D) ($H_2/H_1 = 0.39$, $h/D = 0.375$ & $d/D = 0.016$)

Effect of the penetration depth of the drainage gallery (h)

The relationships between the relative distance (b/B) and the relative uplift pressure (P/H_1) for different values of the relative penetration depth of the gallery (h/D = 0.0, 0.25 & 0.375) are shown in Figure 4. The uplift pressure acting on the dam floor decreases with increasing the relative penetration depth (h/D).

Table 2 Percentage of average reduction in volume of uplift pressures, for h/D = 0.375 and d/D = 0.016

L/D	H_2/H_1				Average percentage (%)
	0.39	0.47	0.53	0.6	
	Percentage of reduction in volume of uplift pressure due to construction of drainage gallery beneath the gravity dam (%)				
0.14	35	34	33	32	34
0.24	23	23	23	24	23
0.29	23	23	22	22	23
0.39	23	23	22	22	23

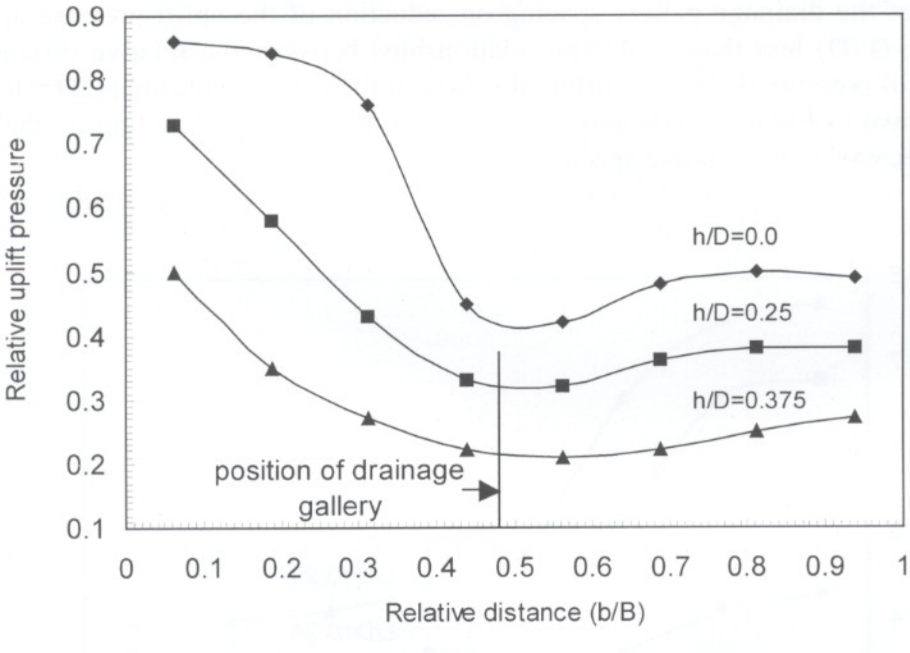

Fig. 4 Relative uplift pressure (P/H_1) versus relative distance (b/B) for different values of the relative penetration depth (h/D) (H_2/H_1 = 0.39, d/D = 0.035 & L/D = 0.39)

The effect of penetration depth of the drainage gallery is summarized in Table 3. With increasing relative penetration depth of the gallery (h/D) from 0.0 to 0.375, the average percentage reduction in the uplift pressure ranges from 25 % to 63 % respectively, and the average value may be considered 40 %. Increasing the penetration depth of the gallery has a good effect on reduction of the uplift force acting on the dam floor.

Table 3 Percentage of average reduction in volume of uplift pressures, for d/D = 0.035 and L/D = 0.39

h/D	H_2/H_1 0.39	H_2/H_1 0.6	Average percentage (%)
	Percentage of reduction in volume of uplift pressure due to construction of drainage gallery beneath the gravity dam (%)		
0.000	26	23	25
0.125	33	31	32
0.250	41	38	40
0.375	64	61	63

From the foregoing discussion, changes in diameter (d), spacing (L), and penetration depth (h) of the drainage gallery would result in the reduction of uplift pressure force. Changes in d, L, and h respectively accounted for 11 %, 25 %, and 40 % reduction in uplift pressure force. It is evident that the most sensitive of these parameters is the penetration depth of the drainage gallery (h).

CONCLUSIONS

In the present experimental work, the effect of the drainage gallery dimensions on the reduction of the uplift pressure acting on the floor of a gravity dam are studied and the following conclusions are made:

1) Increasing the relative diameter of the drainage gallery (d/D) from 0.005 to 0.035 reduces the uplift pressure by values ranges from 3 % to 21 %, and the average value of the reduction in this case may be considered 11 %.

2) For the relative spacing of the drainage gallery (L/D) = 0.14, reduction in the uplift pressure is equal to 34 %. For the relative spacing (L/D) greater than or equal to 0.24, the reduction is constant and equal to 23 %. The average reduction in the uplift pressure due to spacing may be considered 25 %.

3) Relative penetration depth of the drainage gallery (h/D) is the most important parameter in reducing the uplift pressure beneath the dam floor where increasing the value of (h/D) from 0.0 to 0.375 leads to reduction in the uplift pressure ranges from 25 % to 63 %. The average value of the reduction in this case may be considered 40 %.

NOTATION

b	position of the drainage gallery measured from upstream point beneath the dam floor,
B	base width of the gravity dam,
d	drainage gallery diameter,
D	depth of pervious layer,
L	width of the model = spacing of the drainage gallery in the longitudinal direction of the dam,
h	penetration depth of the drainage gallery,
H_1	uplift pressure acting on the heel of the dam,
H_2	uplift pressure acting on the toe of the dam,
P	uplift pressure acting on the dam base,

(P/H_1)	relative uplift pressure,
b/B	relative position of the drainage gallery,
d/D	relative diameter of the drainage gallery,
L/D	relative spacing of the drainage gallery,
h/D	relative penetration depth of the drainage gallery.

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