Optimal Position of Drainage Gallery underneath Gravity Dam

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ABSTRACT

Gravity structures depend mainly upon its own weight to resist the effecting forces, specially upward force. Upward force can be reduced by using a drainage gallery somewhere beneath the floor of the structure. The optimum location of the drainage gallery underneath gravity dam is the goal of this study. This location is denoted by position of maximum reduction in uplift force.

KEYWORDS Seepage, Gravity dam, Uplift pressure, Sand model, Drainage Gallery

INTRODUCTION

Construction of drainage system in gravity dams plays an important role in minimizing uplift force which allow more stability for the dam body. Goodman et al [1] addressed the problem of uplift associated with a crack at the base of a concrete gravity dam. An analytical solution was proposed for the uplift force and overturning moments for a horizontal crack in direct connection with the reservoir. The analytical solution was presented in dimensionless form and was used to show that drains are effective in reducing uplift pressure in cracks in dams. Bernard et al [2] studied the effect of head losses in drain pipes and modeled it to show their effect on crack induced uplift and drain effectiveness. Abd El-Razek M. [3] used a sand model to study case of lining subjected to high uplift pressure, based on minimum uplift force acting on the lining, optimum numbers and positions of relief valves was investigated. A theoretical solution based on seepage theory was presented by Chawla et al [4] to determine the average uplift pressure across the section of gravity dam having a system of equally spaced drains of uniform diameter. The optimal location of the drain for minimum uplift has also been obtained. Raymond et al [5] showed that uplift can be modeled in several ways in a finite element analysis of concrete dams. Also uplift pressure within the rock and concrete and relative foundation stiffness have an affect on the fracture mechanics analysis of the dam foundation interface.

Ref. [6] showed that, at drainage gallery, the recommended uplift pressure is equal to the hydrostatic pressure at toe of dam base plus the third difference of the hydrostatic pressure at heel and toe of the dam base.

In this paper the optimum position of the drainage gallery is experimentally obtained. The value of uplift pressure at the drainage gallery given by Ref. [6] was discussed and another formula was deduced by the authors considering effect of the drainage gallery position.

EXPERIMENTAL SETUP

1. The Sand Model:

The case under study is used to determine the optimum location of the vertical drainage gallery beneath floor of a gravity dam, Figure (1).

The experimental set-up shown in Figure (2) consists of one box divided into three tanks, the first is used to control head upstream the dam model, the second which locates in the middle includes the dam model which rests on a sandy soil (1), and the third one is used to control the downstream head. The partitions between all tanks (2) are perforated and covered with synthetic material to allow only movement of water from upstream to downstream without sand particles.

The model of the dam body is represented by a three perspex plates, two verticals represent upstream and downstream face of the dam and the third is horizontal fixed with the verticals and represents the floor of the dam. The floor of the dam model contains seven vertical perforated tubes (3) covered with the synthetic material which is acting as a filter and each tube is acting as a drainage gallery. A vertical cooper bars with screw ends (4) are used to control the seeping water entering the gallery to flow out of the model. The model also includes eight piezometers (5) are distributed along the floor. Constant head of water upstream or downstream the model can be achieved by using an overflow tube (6). The seepage discharge entering the drainage gallery is measured through an opening in the face of the experimental set-up. Also seepage discharge escaped to the downstream is measured by using an overflow.

Grain size distribution, density and permeability tests of the used sand are tested in the soil mechanics laboratory of Faculty of Engineering of Alexandria University. The grain size distribution curve of the used sand is shown in Fig. (A-1). The specific weight and coefficient of hydraulic permeability are shown in Table (A-1). The experiments are performed in the laboratory of Irrigation and Hydraulics Department of Faculty of Engineering of Alexandria University.

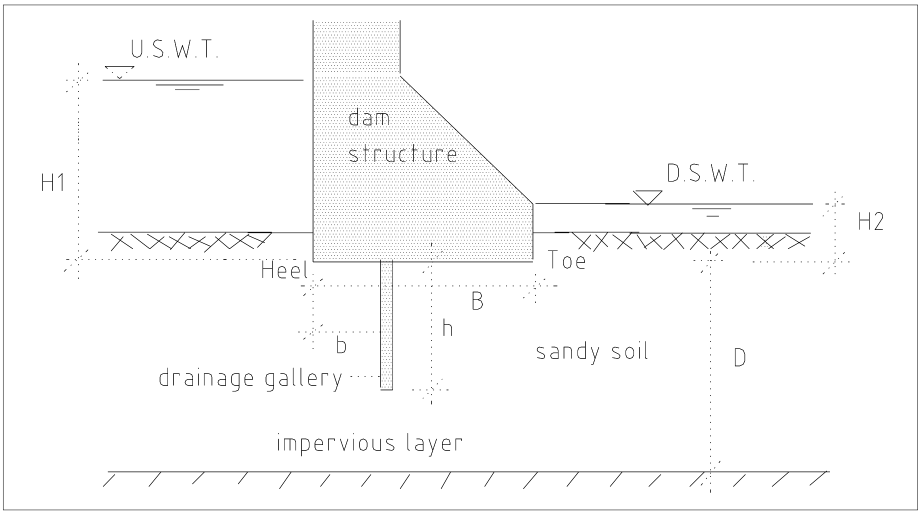

Fig. (1) Cross section of the case under study.

2. Procedure of Experiments:

1. For a constant position, diameter and penetration depth of the drainage gallery, and a constant water head downstream (H_2) and upstream the model (H_1), the uplift pressures acting on the floor of the model are measured using eight piezometers.
2. The water head upstream the model (H_1) is changed several times and step No.1 is repeated.
3. Seven positions for the drainage gallery are tested in this work and steps No.1 and 2 are repeated in each position.
4. In each case mentioned above, the seepage discharge beneath the floor entering the drainage gallery and that escaped downstream are measured.

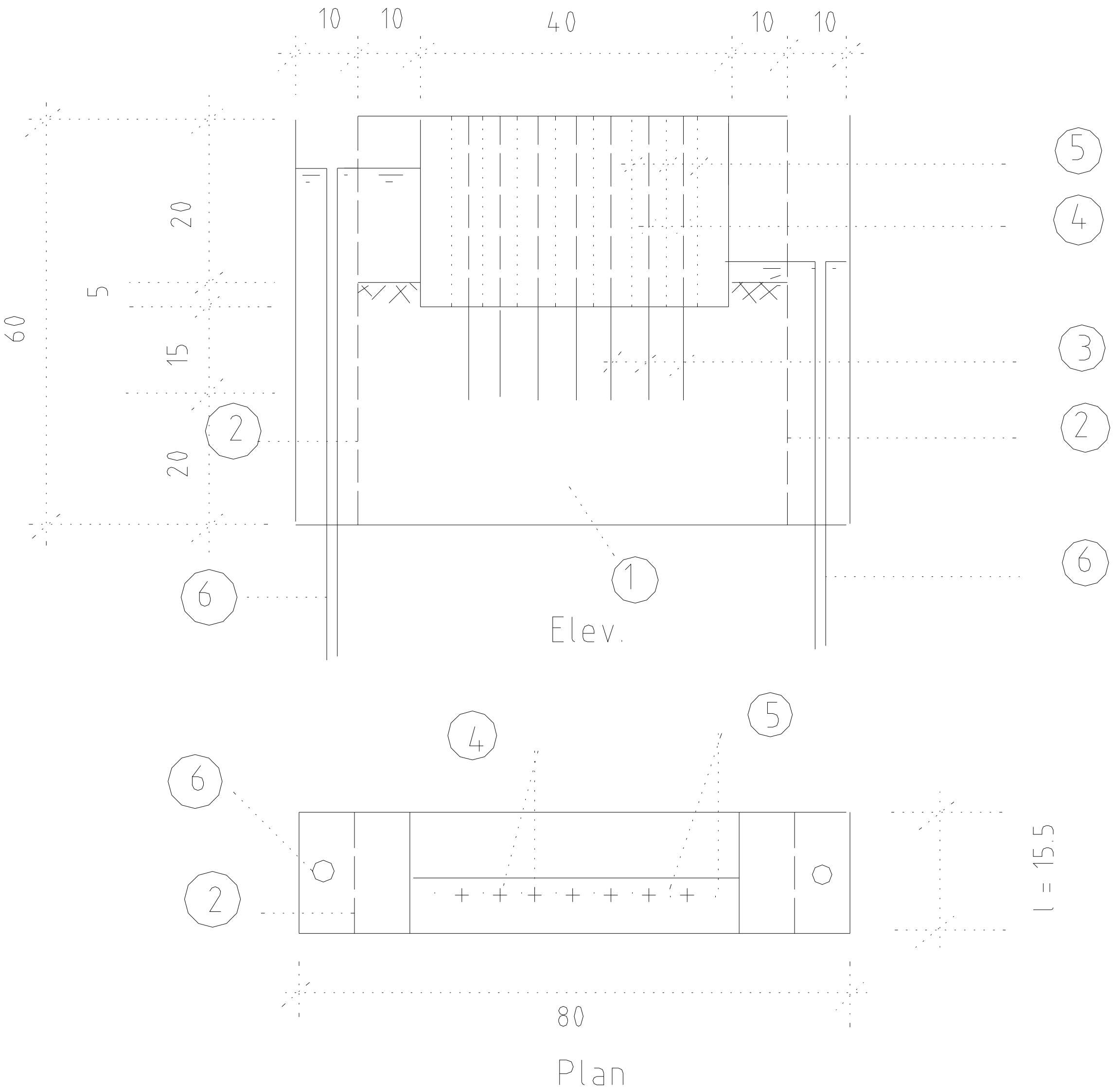

Fig. (2) Experimental set-up (Dimensions in cm).

1. Sand
2. Perforated perspex plate covered with synthetic material
3. Vertical perforated tubes covered with synthetic material
4. Cooper bars with screw ends
5. Piezometers
6. Overflow tube

RESULTS AND ANALYSIS

1. Optimum Position of the Drainage Gallery

Uplift pressures beneath gravity dam model are experimentally recorded and drop due to drainage gallery is noticed as shown in Figure (3). Different locations for the drainage gallery are studied. The volume of uplift pressures in each position of the drainage gallery is calculated and compared with that in case of no drainage gallery. The reduction in volume of uplift pressures due to existing drainage gallery is found.

The results represent percentage of average reduction in volume of uplift pressures, due to drainage gallery construction, are put in Table (1). The optimum position of the drainage gallery is found at b/B = 0.5 at which the average reduction in volume of uplift pressures is maximum and equals 0.54.

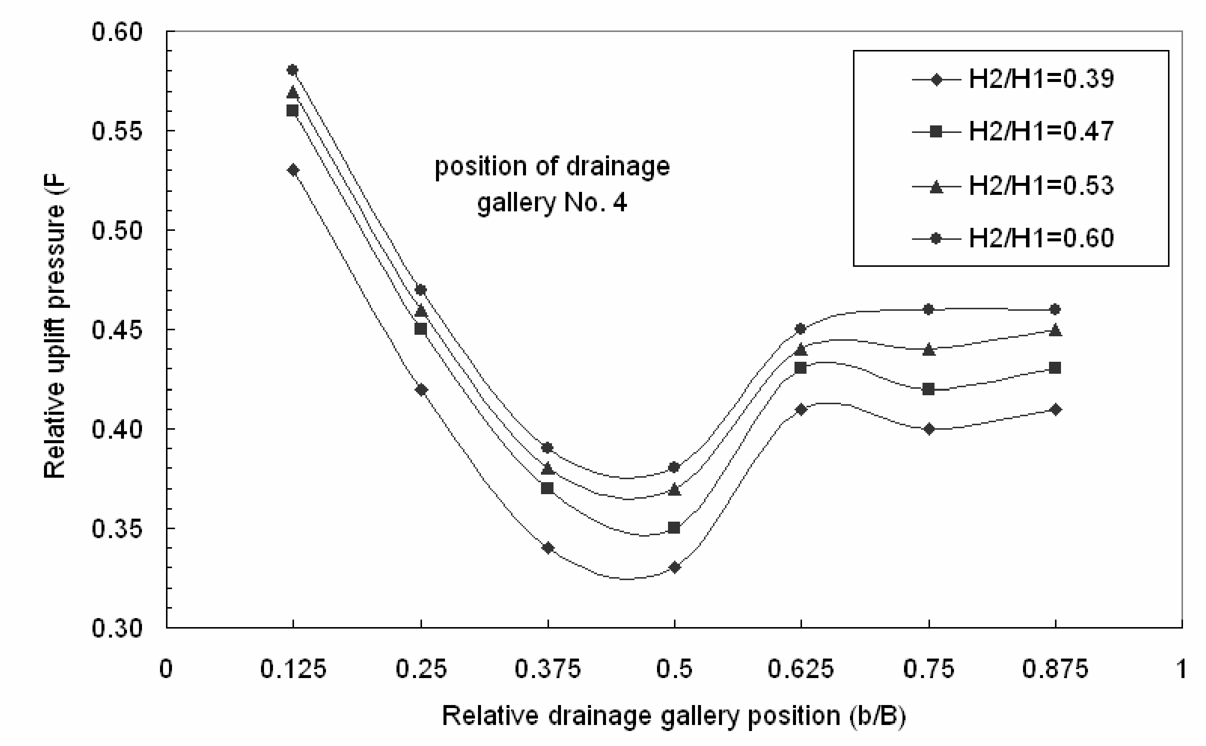

Fig. (3) Relative uplift pressure (P/H_1) versus relative drainage gallery position (b/B) at different values of H_2/H_1.

Table (1). Percentage of average reduction in volume of uplift pressures, for d/l = 0.1

drain No.	Relative drainage position b/B	H_2 / H_1				Average Percentage
		0.39	**0.47**	**0.53**	**0.60**	
		Percentage of reduction in volume of uplift pressures due to construction of drainage gallery beneath gravity dam				
1	0.125	0.350	0.300	0.340	0.348	0.330
2	0.250	0.470	0.460	0.455	0.458	0.460
3	0.375	0.546	0.530	0.530	0.534	0.535
4	0.500	0.548	0.542	0.530	0.530	0.540
5	0.625	0.440	0.450	0.447	0.450	0.450
6	0.750	0.440	0.438	0.439	0.444	0.440
7	0.875	0.330	0.345	0.355	0.365	0.350

2. Uplift Pressure at Drainage Gallery

Based on the experimental data, an empirical equation represents uplift pressure at drainage gallery position, in dimensionless form, is estimated and put in the following form:

$$P/H_1 = C_2\,[C_1 + (H_2/H_1)]/2 \quad \text{(I)}$$

Where:

P is the uplift pressure at the drainage gallery position,

H_1 is the uplift pressure at heel, Fig. (1),

H_2 is the uplift pressure at toe, Fig. (1),

C_1 and C_2 are constants, Fig. (4).

The results of the above equation (I) are put in Table (2) to compare the calculated values of relative uplift pressure with that measured experimentally.

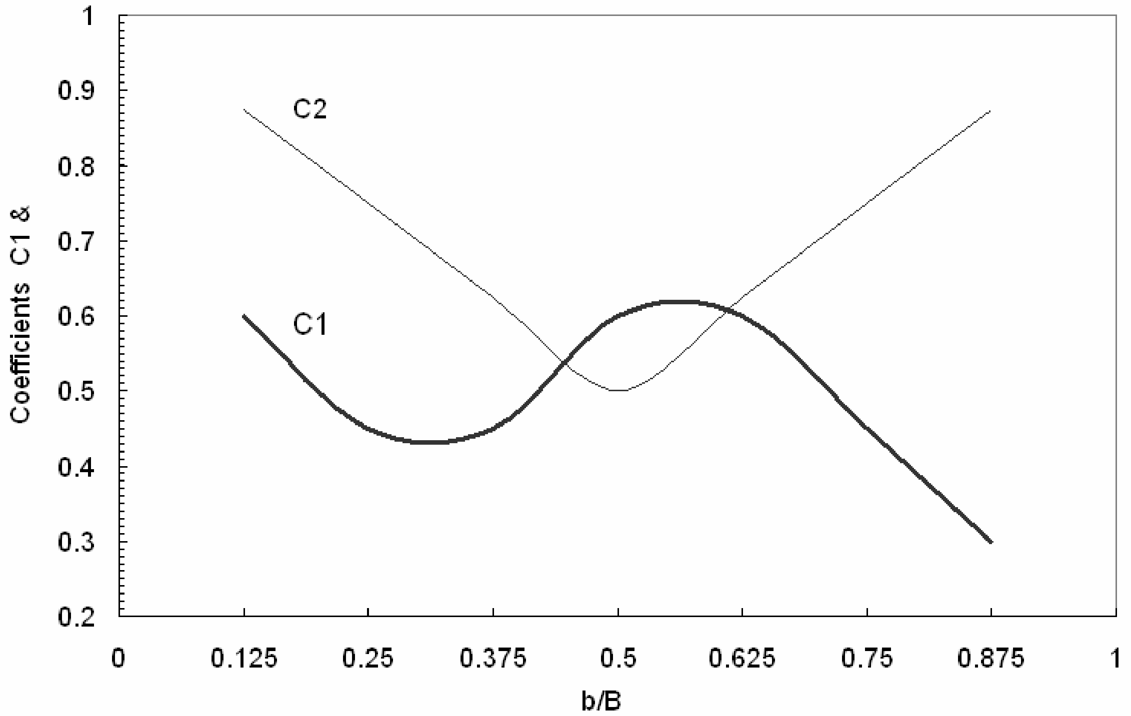

Fig. (4) Values of coefficients C_1 & C_2 versus b/B.

Table (2). The calculated and measured values of relative uplift pressures at different relative positions of drainage gallery

Drain No.	b/B	$H_2/H_1 = 0.39$		$H_2/H_1 = 0.47$		$H_2/H_1 = 0.53$		$H_2/H_1 = 0.60$	
		$(P/H_1)_c$	$(P/H_1)_m$	$(P/H_1)_c$	$(P/H_1)_m$	$(P/H_1)_c$	$(P/H_1)_m$	$(P/H_1)_c$	$(P/H_1)_m$
1	0.125	0.436	0.446	0.472	0.474	0.497	0.485	0.528	0.500
2	0.250	0.315	0.328	0.345	0.358	0.368	0.374	0.394	0.387
3	0.375	0.261	0.259	0.287	0.287	0.306	0.297	0.328	0.307
4	0.500	0.248	0.246	0.268	0.263	0.283	0.282	0.300	0.297
5	0.625	0.312	0.317	0.337	0.339	0.356	0.356	0.378	0.367
6	0.750	0.307	0.317	0.337	0.337	0.359	0.350	0.385	0.370
7	0.875	0.304	0.326	0.339	0.345	0.365	0.359	0.396	0.373

Figure (5) shows the relation between uplift pressure at drainage gallery position according to the calculated values from equation (I) and these measured experimentally.

Equation (I) is compared with that given by Ref. [6] which was put in the following form:

$$P = \gamma_w H_2 + 1/3\,(\gamma_w H_1 - \gamma_w\ H_2)$$

Where:

P is the uplift pressure at drainage gallery position,

H_1 and H_2 are the hydrostatic pressures at heel and toe of the dam base respectively.

It is clear that equation given by Ref. [6] does not take into consideration effect of drainage gallery position (b/B). This effect is taken into account by introducing the constant C_2 which is shown in Figure (4). The coefficients C_1 and C_2 are put emirically based on the experimental data. Table (3) shows that relative uplift pressure (P/H_1) calculated by Ref. [6] does not change as relative position of drainage gallery (b/B) changes, but the value of (P/H_1) given by the authors changes as relative position of drainage gallery (b/B) increases. Equation given by Ref. [6] gives bigger values in uplift pressure than that given by the authors. Table (3) shows that the average difference between them is about 0.27 for $b/B \leq 0.125$ and 0.52 for $0.875 \geq b/B > 0.125$. The formula given by the authors makes design of the gravity dam more economy.

3. Seepage Discharge

Figure (6) shows the relation between relative seepage discharge entering the drainage gallery $(q/kd)_{dr.}$ versus relative position of the drainage gallery (b/B) for H_2/H_1 = 0.39, 0.47, 0.53 and 0.6. It is clear that the maximum seepage discharge entering the drainage gallery occurs at position of b/B = 0.5, at which maximum reduction in volume of uplift pressures occurs. It can be concluded that optimum position of drainage gallery can be found at b/B = 0.5 at which seepage discharge entering the drainage gallery is maximum.

Table (4) shows comparison between relative seepage discharge entering the drainage gallery $(q/kd)_{dr.}$ and that escaped to the downstream $(q/kd)_{d.s.}$ for d/l = 0.1. It is clear that relative seepage discharge escaped to the downstream is almost equal zero. This means that all seepage discharge enter the drainage gallery.

Table (3). Relative uplift pressure calculated by Ref. [6] and the authors at different relative positions of the drainage gallery

Drain No.	b/B	$H_2/H_1 = 0.39$		$H_2/H_1 = 0.47$		$H_2/H_1 = 0.53$		$H_2/H_1 = 0.60$		Average Difference %
		(P/H_1) Ref.[6]	(P/H_1) Authors	(P/H_1) Ref.[6]	(P/H_1) Authors	(P/H_1) Ref.[6]	(P/H_1) Authors	(P/H_1) Ref.[6]	(P/H_1) Authors	
1	0.125	**0.593**	0.436	**0.647**	0.472	**0.687**	0.497	**0.733**	0.528	27.0
2	0.250	**0.593**	0.315	**0.647**	0.345	**0.687**	0.368	**0.733**	0.394	46.6
3	0.375	**0.593**	0.261	**0.647**	0.287	**0.687**	0.306	**0.733**	0.328	55.6
4	0.500	**0.593**	0.248	**0.647**	0.268	**0.687**	0.283	**0.733**	0.300	58.6
5	0.625	**0.593**	0.312	**0.647**	0.337	**0.687**	0.356	**0.733**	0.378	48.0
6	0.750	**0.593**	0.307	**0.647**	0.337	**0.687**	0.359	**0.733**	0.385	47.8
7	0.875	**0.593**	0.304	**0.647**	0.339	**0.687**	0.365	**0.733**	0.396	47.3

Table (4). Comparison between relative seepage discharge entering the drainage gallery $(q/k.d)_{dr.}$ and that escaped to the downstream $(q/k.d)_{d.s.}$ for d/l = 0.1

Drain No.	b/B	$H_2/H_1 = 0.39$		$H_2/H_1 = 0.47$		$H_2/H_1 = 0.53$		$H_2/H_1 = 0.60$	
		$(q/k.d)_{dr.}$	$(q/k.d)_{d.s.}$	$(q/k.d)_{dr.}$	$(q/k.d)_{d.s.}$	$(q/k.d)_{dr.}$	$(q/k.d)_{d.s.}$	$(q/k.d)_{dr.}$	$(q/k.d)_{d.s.}$
1	0.125	13.15	**0.581**	11.61	**0.00**	10.93	**0.00**	10.07	**0.00**
2	0.250	14.00	**0.00**	12.12	**0.00**	10.24	**0.00**	9.56	**0.00**
3	0.375	15.37	**0.00**	14.00	**0.00**	13.32	**0.00**	11.27	**0.00**
4	0.500	15.54	**0.00**	13.32	**0.00**	11.95	**0.00**	11.10	**0.00**
5	0.625	15.20	**0.00**	12.29	**0.00**	11.27	**0.00**	10.59	**0.00**
6	0.750	12.63	**0.00**	11.27	**0.00**	10.76	**0.00**	9.22	**0.00**
7	0.875	12.29	**0.686**	10.93	**0.273**	9.73	**0.00**	8.88	**0.00**

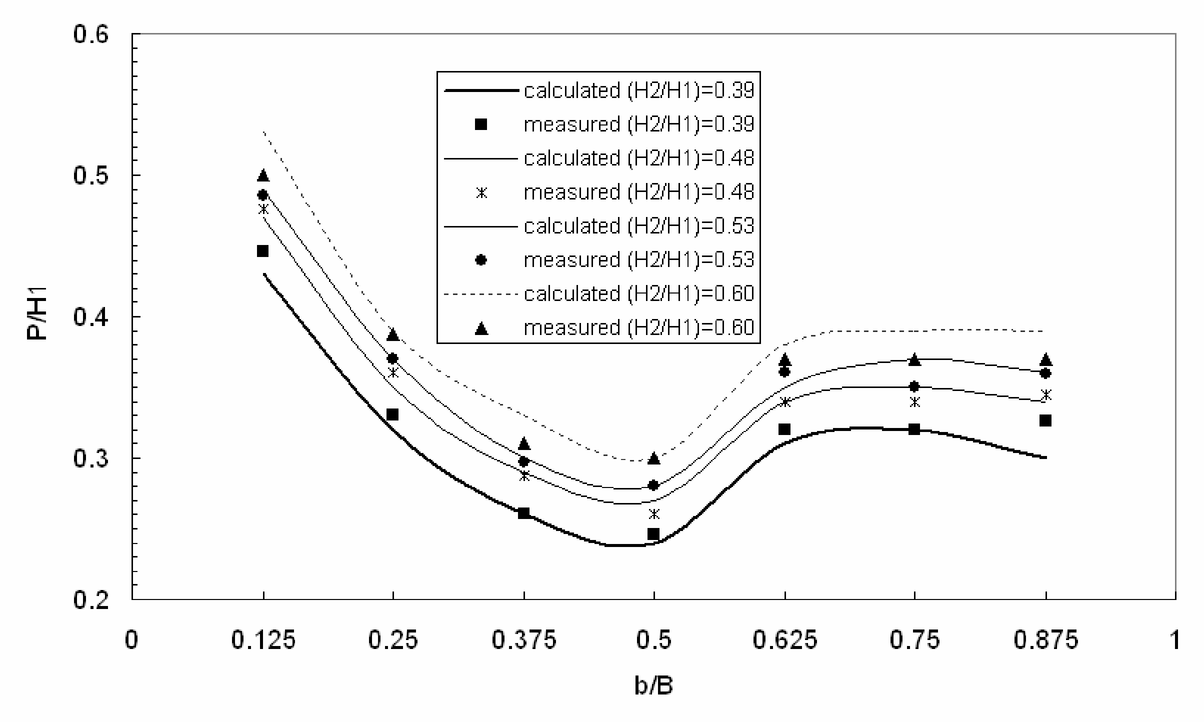

Fig. (5) The calculated and measured relative uplift pressures (P/H_1) versus relative position of the drainage gallery (b/B) for $H_2/H_1 = 0.39$, 0.48, 0.53 and 0.6

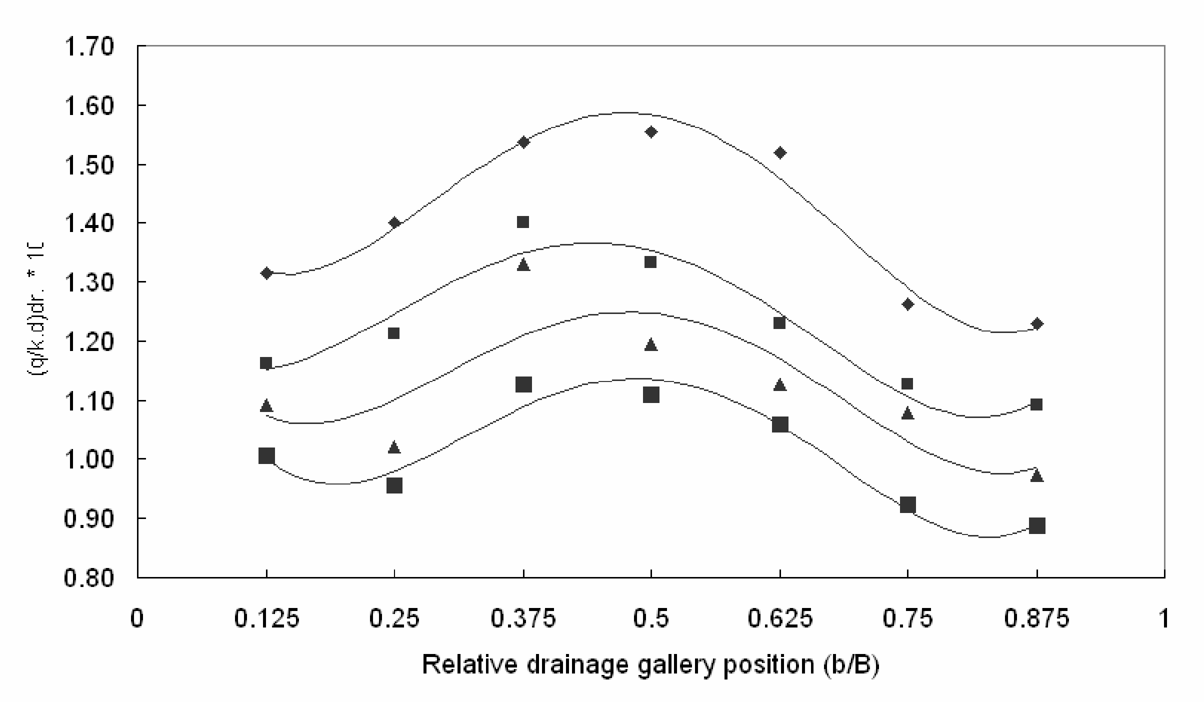

Fig. (6). Relative seepage discharge entering drainage gallery $(q/k.d)_{dr.}$ versus its relative position (b/B)

CONCLUSIONS

Minimizing uplift pressures beneath gravity dam is the goal of this paper. Different positions of the drainage gallery are carried out experimentally and the following conclusions are made:

1. The optimum position of the drainage gallery, constructed beneath gravity dam, is found at $b/B = 0.5$ at which reduction in volume of the uplift pressures is maximum and equals about 0.54.
2. An empirical formula, based on the experimental data, is deduced in dimensionless form to calculate value of uplift pressure at drainage gallery position.
3. A comparison between the deduced formula by the authors and that given by Ref. [6] is made where effect of drainage gallery position is cosidered in the first formula and neglected in the second. Formula given by Ref. [6] gives bigger value, in uplift pressure at drainage gallery position, than that given by the authors. The average difference between the two values of uplift pressure in the two formulae is about 0.27 for $b/B \leq 0.125$ and 0.52 for $0.875 \geq b/B > 0.125$. Then, the formula given by the authors makes design of the gravity dam more economy.
4. The optimum position of the drainage gallery can be achieved at $b/B = 0.5$, at which seepage discharge entering the drainage gallery is maximum.

RECOMMENDATION

Spacing, diameter and penetration depth of the drainage gallery must be studied in future.

NOMENCLATURE

b	position of drainage gallery measured from upstream point beneath the dam,
B	base width of the gravity dam, Fig. (1),
d	drainage gallery diameter,
D	depth of pervious layer (sandy soil),
l	width of the model, Fig. (2),
h	penetration depth of the drainage gallery,
k	hydraulic permeability of the used soil,
H_1	uplift pressure acting at the upstream point of the dam base (heel),
H_2	uplift pressure acting at the downstream point of the dam base (toe),
P	uplift pressure acting at the dam base,

$(P/H_1)c$	calculated values of relative uplift pressure given by equation (I),
$(P/H_1)_m$	experimentally measured values of relative uplift pressure,
$(q/k.d)_{dr.}$	relative seepage discharge entering drainage gallery,
$(q/k.d)_{d.s.}$	relative seepage discharge escaped to the downstream side,
b/B	relative drainage gallery position,
γ_w	specific weight of water.

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