EXPERIMENTAL STUDY FOR SEEPAGE CHARACTERISTICS BENEATH HYDRAULIC STRUCTURES WITH DROPPING FLOORS

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ABSTRACT

The present study is intended to investigate the characteristics of seepage beneath dropping floors. The floor is provided with one row sheetpiling located at the floor toe. The experimental program includes, sheetpile depth, depth and position of the floor drop as parameter variables to be investigated. Experiments were conducted using the Hele-Shaw model with motor's oil as a viscous flow. Charts and curves describing the effect of the floor drop on the seepage quantity, potential values at the extreme points of the bottom contour of the floor and the loss of head along the drop are given for various depths and positions of the floor drop.

NOTATIONS

- b Distance between the two prespex sheets of the model,
- D Depth of the floor drop,
- g Gravity acceleration,
- H Total effective head,
- ΔH Loss of head along the floor drop,
- h Potential head at any point along the under-side of the floor,
- k Hydraulic conductivity, $k = g\,b^2/12\,\nu$, cm/sec,
- L Length of floor,
- q Quantity of seepage per unit width,
- S Depth of the toe sheetpile,
- t Depression depth of the floor in the permeable layer,
- x Distance between the upstream edge of floor and the location of the floor drop,
- ν Kinematic viscosity of the oil, cm^2/sec.

1. INTRODUCTION

Structures with dropping floors have wide applications in the practice of hydraulic structures, such as; overfall weirs, spillways, pump stations and locks. Figure (1) shows an example for a hydraulic structure with dropping floor. Generally, providing the floors of hydraulic structures with sheetpiles is highly important in practice, since gradients at the upstream and downstream edges of the floor possess very high values. According to Terzaghi's theory [1], the force exerted on the grains of a pervious soil is proportional to the gradient. At the upstream end of the floor, this force is infinitely high, however it works downwards. Meanwhile it does not affect soil grains stability. On the other hand, at the downstream end of the floor, this force is directed upwards, lifting the soil particles which causes piping to take place, even under low heads. Therefore, providing dropping structures with sheetpiles, located at the toe gain its importance on two grounds; a) it protects the structure against piping or heave. b) it gives the soil underneath the floor more stability against the movement of scour hole at the downstream side.

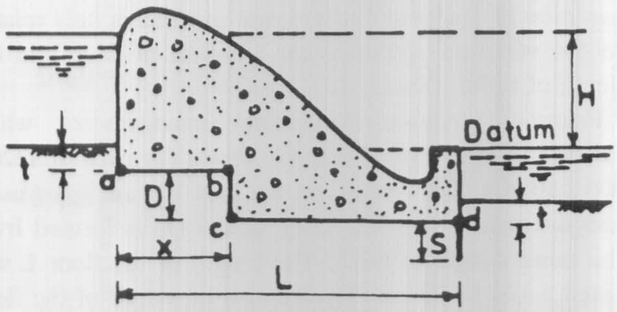


Figure 1. Definition sketch for hydraulic structure with dropping floor.

The problem of seepage beneath dropping floor with intermediate sheetpile located at the floor drop has been studied theoretically. Bazanov [2] applied the method of Pavlovsky [3] to the seepage under a single stepped overfall, with, and without cut-off. He introduced graphs to calculate the seepage discharge. The same scheme had been examined by Zamarin [4,5] for structures rest on pervious strata of infinite depth. A conformal mapping technique was used to calculate the uplift pressure at the extreme points of the bottom contour of drop structure with one sheetpile fixed at the drop [6].

The problem of seepage beneath hydraulic structures with dropped floors ended with toe sheetpile has not been studied, previously. Therefore, this important problem is treated in the present study. The effect of the depth and the position of the floor drop on the seepage characteristics (seepage rate and potentials) for different depths of the sheetpile located at the toe of the dropping floor are experimentally studied.

2. EXPERIMENTAL PROCEDURE

The characteristics of seepage underneath gravity structure with dropping floor are studied experimentally using the Hele-Shaw model. In order to be free from any boundary effect, the dimensions of the model are taken according to the recommended dimensions reported in [7] as follows;

1. The minimum length of both upstream and downstream seepage faces is chosen five times the half length of the floor L.
2. The depth of the permeable layer underlying the structure is greater than five times the depth of sheetpile.

Accordingly, the permeable layer is assumed to be infinitely deep and the boundaries must have no effect on the values of potentials and seepage rate. In this case the variation of potential and seepage quantity is only related to the variation of depth and position of drop and the depth of the toe sheetpile.

Figure (2). shows the model arrangements, which consists of two vertical prespex sheets (1) each of 1320 x 800 x 10 mm. The two sheets are kept 1.5 mm apart using klingarite sheet (2). The floor model (3) is formed from the same klingarite sheet. The length of the floor L was taken equal to 20 cm. The depression depth of the floor model in the permeable layer t is taken equal to 0.5 cm representing a ratio of t/L equals to 2.5%. The upstream seepage face is fed by oil from elevated tank (4). Upstream and downstream sides are provided with tanks (5) and (6) with overflow tubes (7) and (8) to maintain constant levels at the two sides. These tubes could be moved vertically to change the effective head if required. The overflowing oil from the downstream tube is measured using graduated tube (9) to give the seepage quantity. The overflowing oil from the tubes is collected in tank (10), from which the oil is dispatched to the elevated tank by pump (11). The flowing oil supper 7500-20w 150 is considered viscous flow. Potentials along the floor are measured by pizometers (12), which are made by slotting the model at the extreme points of the underside of the floor (a,b,c and d) and between them. Each slot is 2 mm wide.

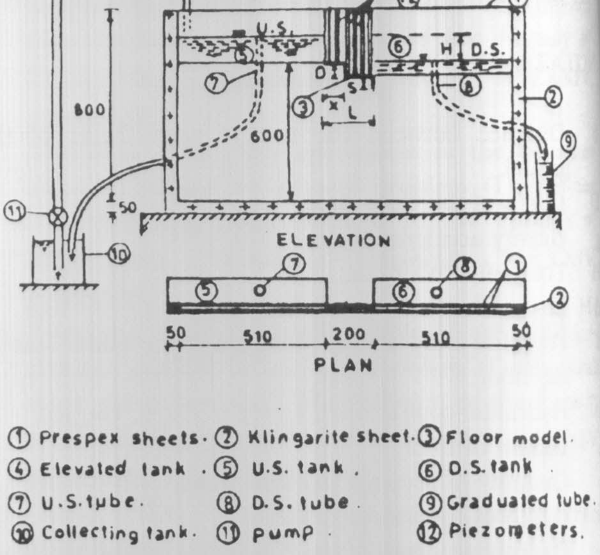


Figure 2. Experimental model.

The experiments are conducted by lowering th downstream face of the model to create the floor dro The depth of the floor drop D was taken according to th ratio D/L equals to 0.125, 0.25, 0.375 and 0.5. For each the above values, the distance between the position of th floor drop and the upstream edge of the floor x varies follows, x/L = 0.0, 0.2, 0.4, 0.6 and 0.8. For each relati position of the floor drop x/L, the floor is provided wi toe sheetpile having a relative depth S/D equals to 0 0.25, 0.5, 0.75 and 1.0. For each depth of the sheetpile the quantity of seepage is recorded and the values potentials along the floor length are measured.

3. ANALYSIS OF RESULTS AND DISCUSSION

3.1 Effect of the Floor Drop on the Seepage Quantity

The experimental results indicate that, changing the position of the floor drop gives poor effect on the seepage quantity. However, this effect increases as the depth of the floor drop increases. As shown in Figure (3), the seepage quantity slowly increases as the relative position of the floor drop x/L increases. The average value of q/KH is calculated from values correspond to x/L equals to 0.0, 0.2, 0.4, 0.6 and 0.8. The average value of q/KH is compared with the minimum and the maximum values of q/KH obtained with respect to x/L equals to 0.0 and 0.8. The comparison showed a deviation of ±0.5, ±1.0, ±1.5 and ±2.0 % with relative depth of the floor drop D/L equals to 0.125, 0.25, 0.375 and 0.5, respectively.

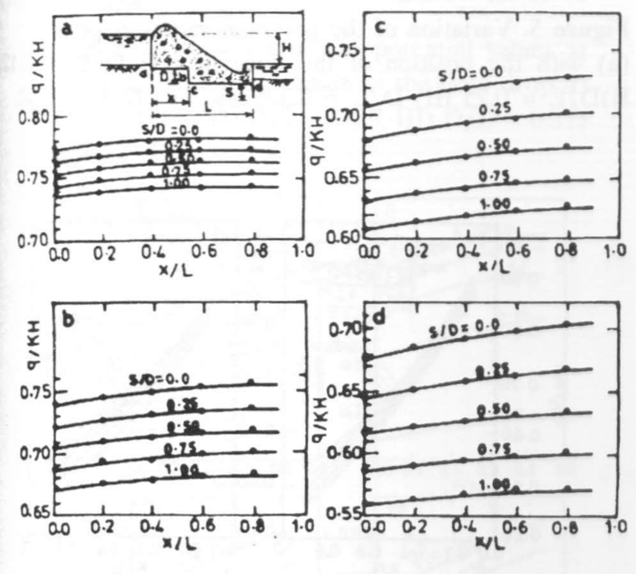


Figure 3. Variation of seepage discharge with the position of the floor drop, a) D/L = 0.125, b) D/L = 0.25, c) D/L = 0.375 and d) d/L = 0.50.

The variation of the depth of the floor drop yields remarkable influence on the seepage discharge as shown in Figure (3). The results show that the seepage discharge decreases as the depth of the floor drop increases. For dropping floor without toe sheetpile, the values of q/KH corresponding to relative depth of the floor drop D/L equals to 0.125, 0.25, 0.375 and 0.5 are compared with the values of q/KH for flat floor, without drop (D/L = 0). The comparison proved that,increasing the depth of the floor's drop decreases the value of q/KH by 5.0, 8.5, 12, and 15 % with respect to the above values of D/L.

Due to the negligible effect of the position of floor drop on the seepage quantity, the average values of q/KH are plotted versus the relative depth of the floor drop D/L as shown in Figure (4). It is clear that, the increase of the depth of the floor drop produces a noticeable decrease in the seepage quantity for different relative depths of the toe sheetpile S/D. The extrapolation of S/D curves intersect at one point on the axis D/L = 0.0 with q/KH value equals to 0.814 which is the same value previously obtained for flat floor without drop or sheetpile [8].

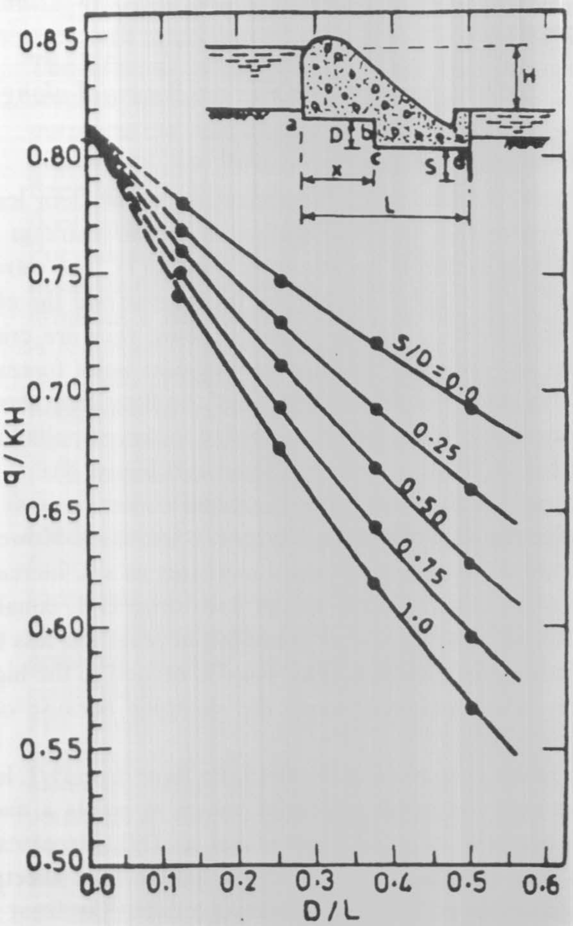


Figure 4. Variation of seepage discharge with relative depth of the floor drop.

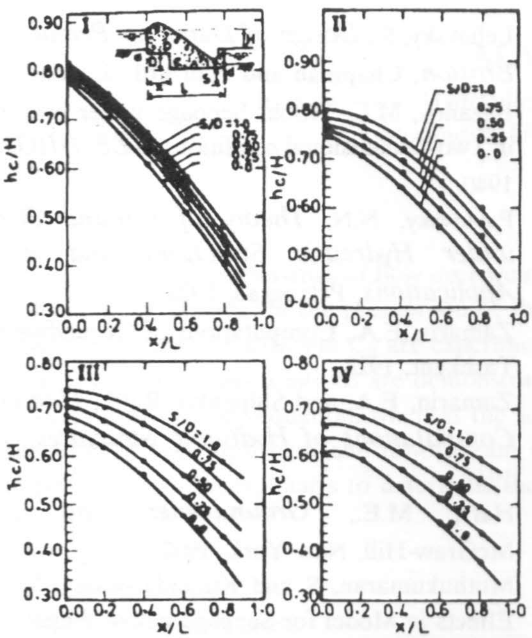


Figure 7. Variation of the potential values at point (C) with the position of the floor drop, I) D/L = 0.125, II) D/L = 0.25, III) D/L = 0.375 and IV) D/L = 0.50.

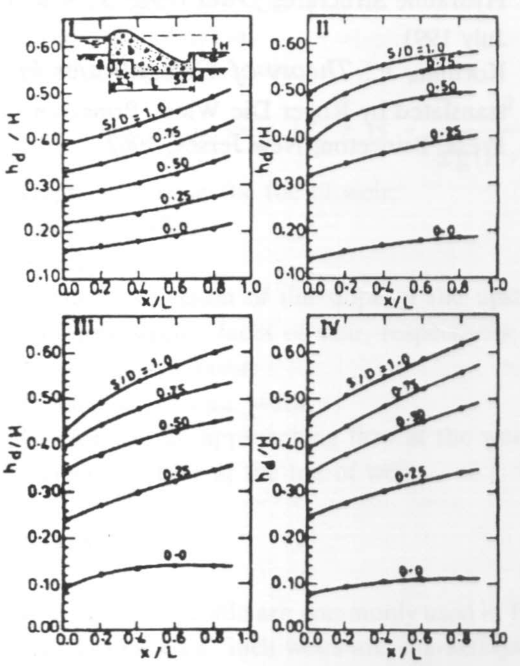


Figure 8. Variation of the potential values at point (d) with the position of the floor drop, I) D/L = 0.125, I) D/L = 0.25, III) D/L 0.375 and IV) D/L = 0.50.

For S/D > 0.0, the potential at point d increases as D/L increases. The toe sheetpile is more effective than the floor drop on the potential values at point d. The increasing rate of the potential at point d due to the toe sheetpile decreases as the relative depth S/D increases.

The variation of the toe sheetpile depth showed considerable influence on the potential values at a, b, c and d. However this effect is higher at point d compared with other extreme points.

The loss of potential ΔH along the floor drop (h_b-h_c) is plotted against the relative position of the floor drop x/L as shown in Figure (9). Figure (9) shows that the minimum value of $\Delta H/H$ occurs at $x/L \approx 0.5$ for $D/L < 0.25$. When $D/L > 0.25$, the minimum value of $\Delta H/H$ takes place when the floor drop is located close to the downstream end of the floor or when $x/L \approx 0.8$.

4. CONCLUSIONS

The seepage characteristics beneath hydraulic structures with dropping floors are experimentally studied. The following conclusions may be practically considered in the design of such structures :

1. The influence of the position of the floor drop on the seepage quantity is negligible. Hence, for design purposes the magnitude of the discharge for any position of the floor drop may be considered for floor with a drop located at the mid-point of the floor length.
2. For constant value of the thickness of pervious foundation, the variation of the depth of the floor drop has a considerable effect on seepage quantity. A reduction of seepage quantity is about 15 % when the depth of the floor drop equals to half length of floor without toe sheetpile.
3. The potential along the floor increases as the floor drop moves towards the upstream edge, while it decreases at the floor toe. Therefore, it is practical to locate the floor drop closer to the upstream edge of floor.
4. Increasing of the depth of the floor drop increases the potential on the front side, and decreases the potential at the backside related to the drop respectively.
5. For floors without toe sheetpile, the potential decreases at the toe as the depth of the floor drop increases. When the floor has a toe sheetpile, the potential at the toe increases as the depth of the floor drop increase.
6. The maximum loss of potential along the floor drop occurs when the floor drop moves towards the upstream side.
7. Charts to determine the seepage quantity and potential for different depths of the floor drop are

The change of the toe sheetpile depth, also has a considerable effect on the seepage quantity. The values of q/KH for dropping floor with relative sheetpile depth S/D equals to 0.25, 0.50, 0.75 and 1.0 are compared with values obtained when S/D equals to zero. The comparison showed a decrease in q/KH values of (1.3, 2.4, 3.7 and 5.0 %), (2.5, 5.0, 7.2 and 9.6 %), (3.75, 7.4, 10.7 and 14.0) and (4.9, 9.5, 14.0, and 18.0 %) occurred with respect to relative depth of the floor drop D/L equals to 0.125, 0.25, 0.375 and 0.5.

The negligible effect of the floor drop position on the seepage quantity in case of dropping floor is similar to the poor effect of the sheetpile position in flat floor without drop. However, the maximum value of q/KH occurs when the location of the floor drop is at, or closed to the toe. For the case of flat floor with sheetpile, the maximum value q/KH takes place if the sheetpile is placed at the center of the floor [9]. This behaviour may be related to the influence of sheetpile's double side effect on the seepage path.

3.2 Effect of the Floor Drop on Potential along the Floor

Potential values along the under-side of the floor length were measured. The flow surface at the downstream side was taken as datum, as shown in Figure (1). The extreme points a, b, c and d are chosen to demonstrate the effect of the floor drop on the potential, since they are critical points for designing the structure against uplift forces.

Variation of position and depth of the floor drop showed a remarkable effect on the potential values at points a, b, c and d as shown in Figure (5 through Figure 8).

Potential values at points a, b and c decreases as the relative position of the floor drop x/L increases. However, at point d the potential values increases as x/L increases. When the relative depth of the floor drop D/L equals to 0.5, the decreasing rate of potentials at point a is less than the other ratios of D/L. This may be related to the higher losses of the potential along the sheetpile because of its longer depth.

Increasing the relative depth of the floor drop D/L leads to an increase in the potential values at points a and b. The potential at point c decreases as D/L increases. In this case the floor drop behaves similar to a sheetpile, which causes an increase in the potential at the front side whereas it decreases the potential at the backside of the sheetpile.

Potential values at point d decrease as the relative depth of the floor drop D/L increases only when S/D = 0.0.

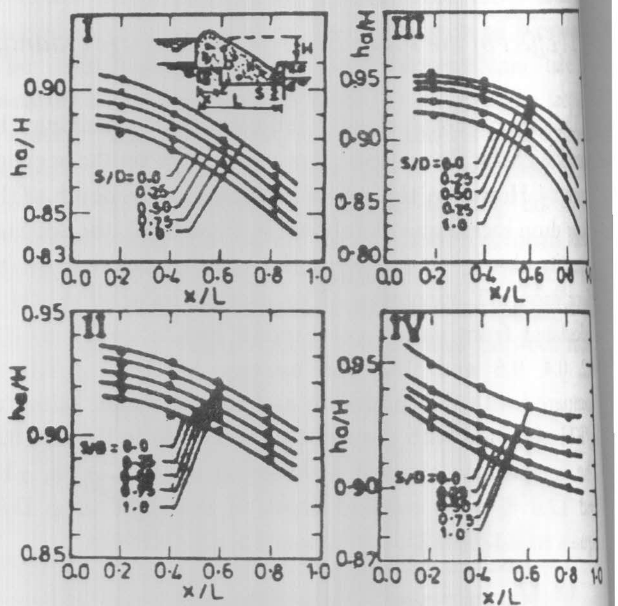


Figure 5. Variation of the potential values at point (a) with the position of the floor drop, I) D/L = 0.125 II) D/L = 0.25 III) D/L = 0.375 and IV) D/L = 0.50.

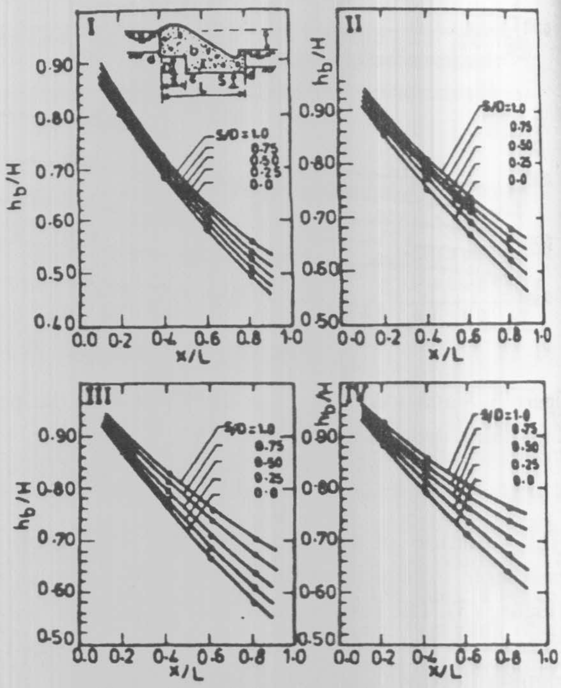
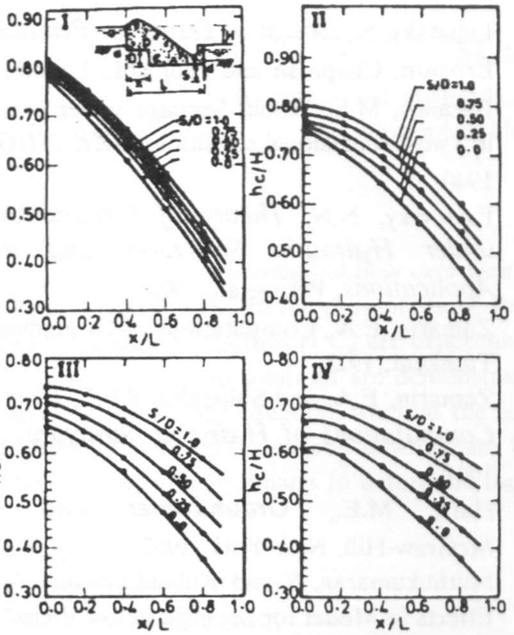


Figure 6. Variation of the potential values at point (b) with the position of the floor drop, I) D/L = 0.125, II) D/L = 0.25, III) D/L = 0.375 and IV) D/L = 0.50.



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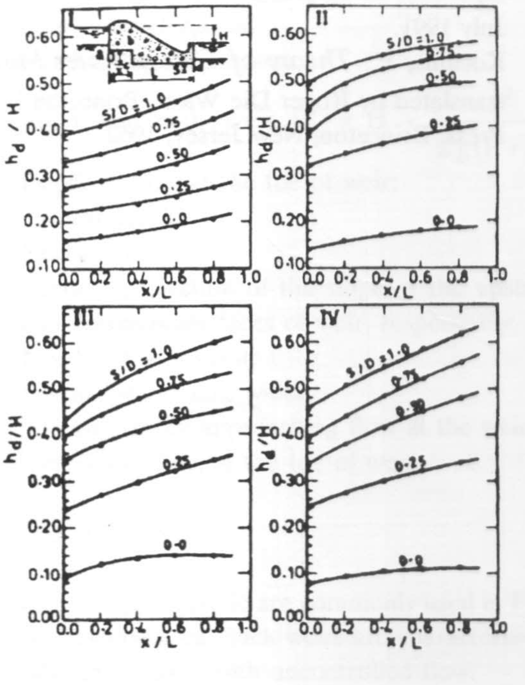

Figure 8. Variation of the potential values at point (d) with the position of the floor drop, I) D/L = 0.125, I) D/L = 0.25, III) D/L 0.375 and IV) D/L = 0.50.

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7. Charts to determine the seepage quantity and potential for different depths of the floor drop are

illustrated in Figs. 4, 5, 6, 7 and 8.

8. In summary, this study strongly suggests that, keeping the floor drop closer to or at the upstream edge of the floor is the optimal location for design purposes.

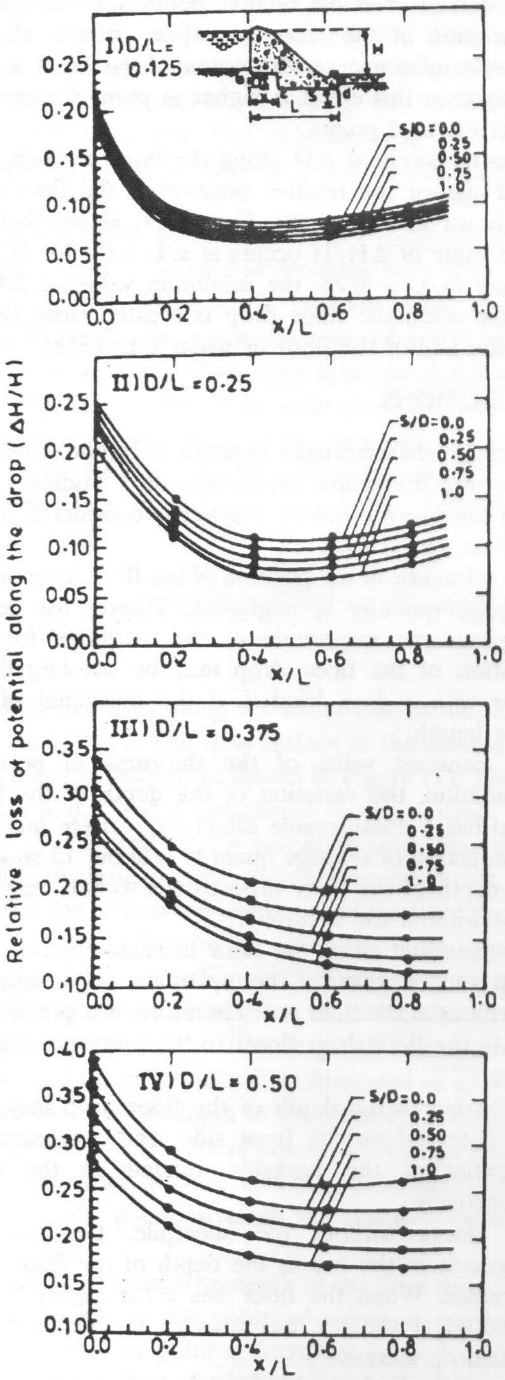

Figure 9. Loss of potential along the floor drop versus its position.

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