

UPLIFT PRESSURES UNDER WEIRS WITH THREE SHEET PILES.

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Introduction.

In a series of papers published in these *Proceedings*¹ and in the *Memoirs of the Punjab Irrigation Research Institute*,² the results of extensive investigations on uplift pressures under simple floors, under weirs with one sheet pile³ and under weirs with two sheet piles⁴ have been reported. In the present paper, the investigation has been extended to the case of weirs with three sheet piles. This case is of considerable practical importance, as many of the weirs constructed in India and abroad have three or even four sheet piles.

Experimental.

The technique of the method employed is essentially the same as that described in the first paper of the series.¹ In all the cases investigated, the impervious floor BF in the model (Fig. 1) was 12" long. Each of the two sheet piles l_1 and l_3 at the heel and the toe, was 2" long and their position and length were not altered throughout the investigation. The varying factor was the intermediate sheet pile l_2 , the length and position of which was altered.

In the first set of observations, the sheet pile l_2 was fixed half way between the heel and the toe sheet piles and seven cases were investigated, the length of l_2 in each case being 0.5", 1.0", 1.5", 2.0", 3.0", 4.0" and 5.0". In the second set of observations, the sheet pile l_2 was shifted by 1.5" towards the heel sheet pile l_1 , and the effect of varying its length on the uplift pressures was investigated as before. Two similar sets of observations were taken by shifting the intermediate sheet pile l_2 towards the heel sheet pile l_1 in two equal steps of 1.5". The four positions of the sheet pile l_2 are shown

by the lines CD, C_1D_1 , C_2D_2 and C_3D_3 in Fig. 1. Thus a total number of twenty-eight cases was investigated. Equi-potential lines were plotted for decrements of 5% of pressure. One set of pressure contours is shown in Fig. 2,

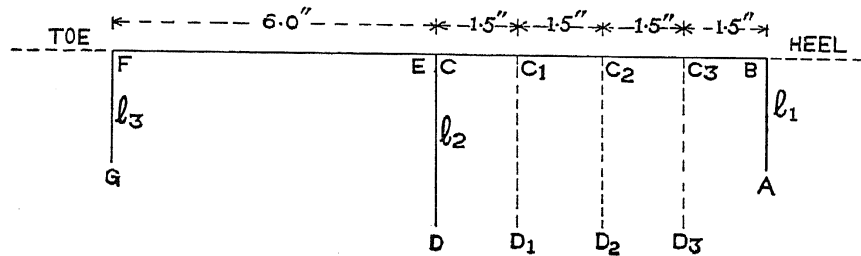


FIG. 1.

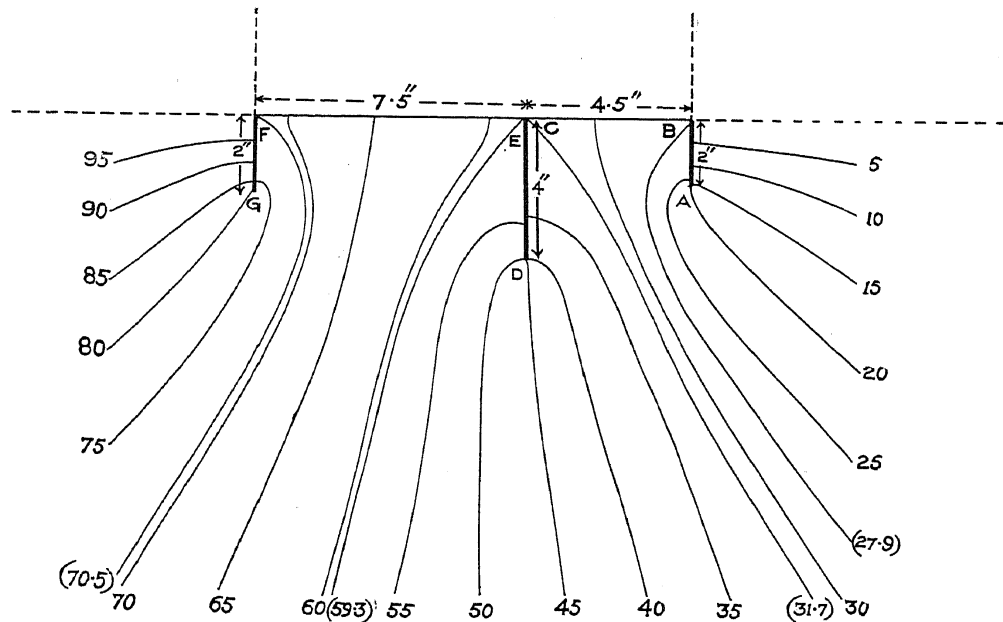


FIG. 2.

as an illustration. For the purpose of design it is sufficient to know the hydraulic gradient under the floor and the pressures at certain points A, B, C, D, E, F and G (Fig. 1) which are reference points in connection with design. These pressures are shown below in the results.

Results.

The pressures at the points A, B, C, D, E, F and G are given in tables I-IV and the variation of pressure from point to point under the floor in Figs. 3-6.

TABLE I.

$$L = 12.0", l_1 = l_3 = 2.0", d_1 = d_2 = 6.0".$$

Pressures at

l_2	A	B	C	D	E	F	G
0.5"	76.7	66.3	52.5	50.0	47.7	33.5	22.7
1.0	76.8	66.7	53.7	50.0	45.9	32.7	22.7
1.5	76.9	67.2	55.9	50.0	44.2	32.5	22.4
2.0	77.0	67.4	57.5	50.0	42.3	32.1	22.1
3.0	77.5	69.1	60.7	50.0	39.1	30.7	21.4
4.0	78.7	70.9	63.4	50.0	36.1	28.6	20.8
5.0	80.0	72.5	66.1	50.0	33.6	27.0	19.6

TABLE II.

$$L = 12.0", l_1 = l_3 = 2.0", d_1 = 4.5", d_2 = 7.5".$$

Pressures at

l_2	A	B	C	D	E	F	G
0.5"	76.8	66.8	57.2	55.0	53.0	33.2	22.8
1.0	76.8	66.9	58.9	55.1	51.2	33.2	22.8
1.5	76.9	67.9	60.5	55.1	49.7	32.9	22.7
2.0	77.1	68.3	62.3	55.3	47.7	32.5	22.8
3.0	77.7	70.5	64.9	54.5	44.6	31.3	22.1
4.0	78.6	72.1	68.3	54.5	40.7	29.5	20.8
5.0	81.0	74.4	71.6	54.4	37.4	27.9	20.0

TABLE III.

$$L = 12.0", l_1 = l_3 = 2.0", d_1 = 3.0", d_2 = 9.0".$$

Pressures at

l_2	A	B	C	D	E	F	G
0.5"	76.5	66.7	61.7	60.0	57.8	33.5	23.3
1.0	76.9	67.9	63.9	60.2	56.8	33.5	23.1
1.5	76.9	68.2	65.2	60.0	55.0	33.4	22.5
2.0	77.3	69.7	67.4	60.0	53.1	32.8	22.1
3.0	79.0	72.1	71.1	60.9	49.5	31.2	21.5
4.0	79.4	75.0	73.9	58.3	45.7	30.3	21.0
5.0	82.3	77.3	76.7	58.0	41.4	28.3	19.7

TABLE IV.

$$L = 12.0", l_1 = l_3 = 2.0", d_1 = 1.5", d_2 = 10.5".$$

Pressures at

l_2	A	B	C	D	E	F	G
0.5"	76.3	67.0	66.0	64.0	62.7	33.2	23.0
1.0	76.7	68.3	68.2	65.3	61.8	33.3	23.0
1.5	77.2	70.0	69.8	66.0	60.0	33.3	22.9
2.0	77.5	71.7	71.5	66.1	58.5	33.0	22.7
3.0	80.0	76.3	76.0	65.7	55.0	32.1	22.0
4.0	82.2	79.5	79.3	63.8	50.1	30.0	21.2
5.0	84.0	82.6	82.3	61.8	45.8	28.6	19.8

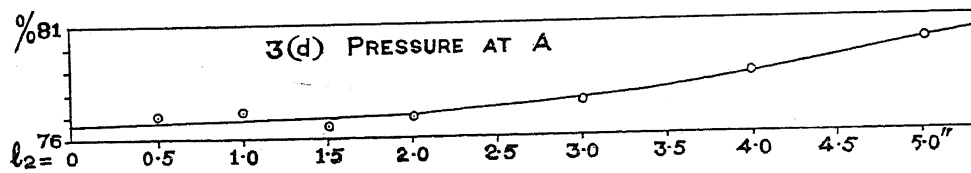
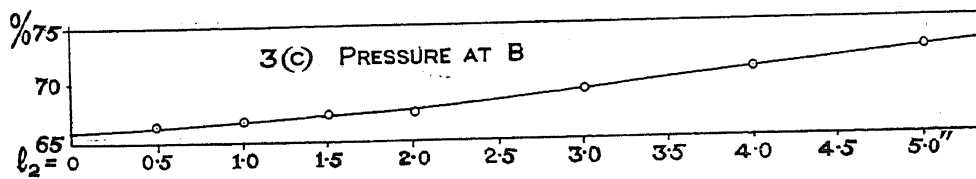
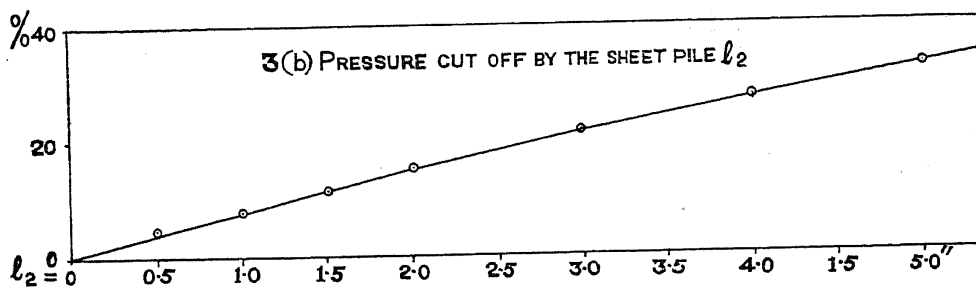
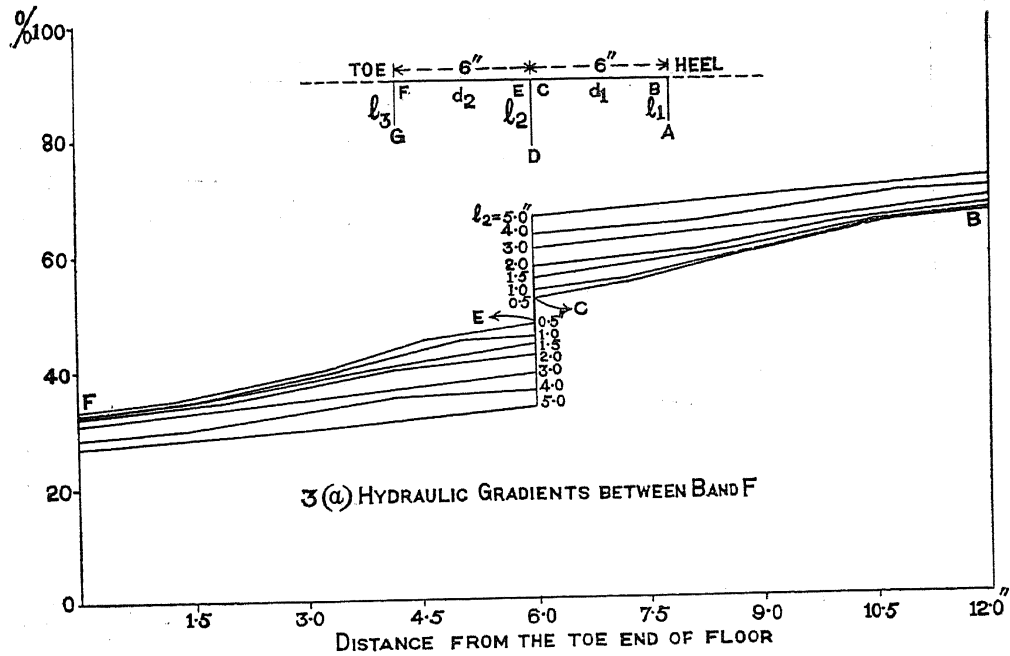


FIG. 3.

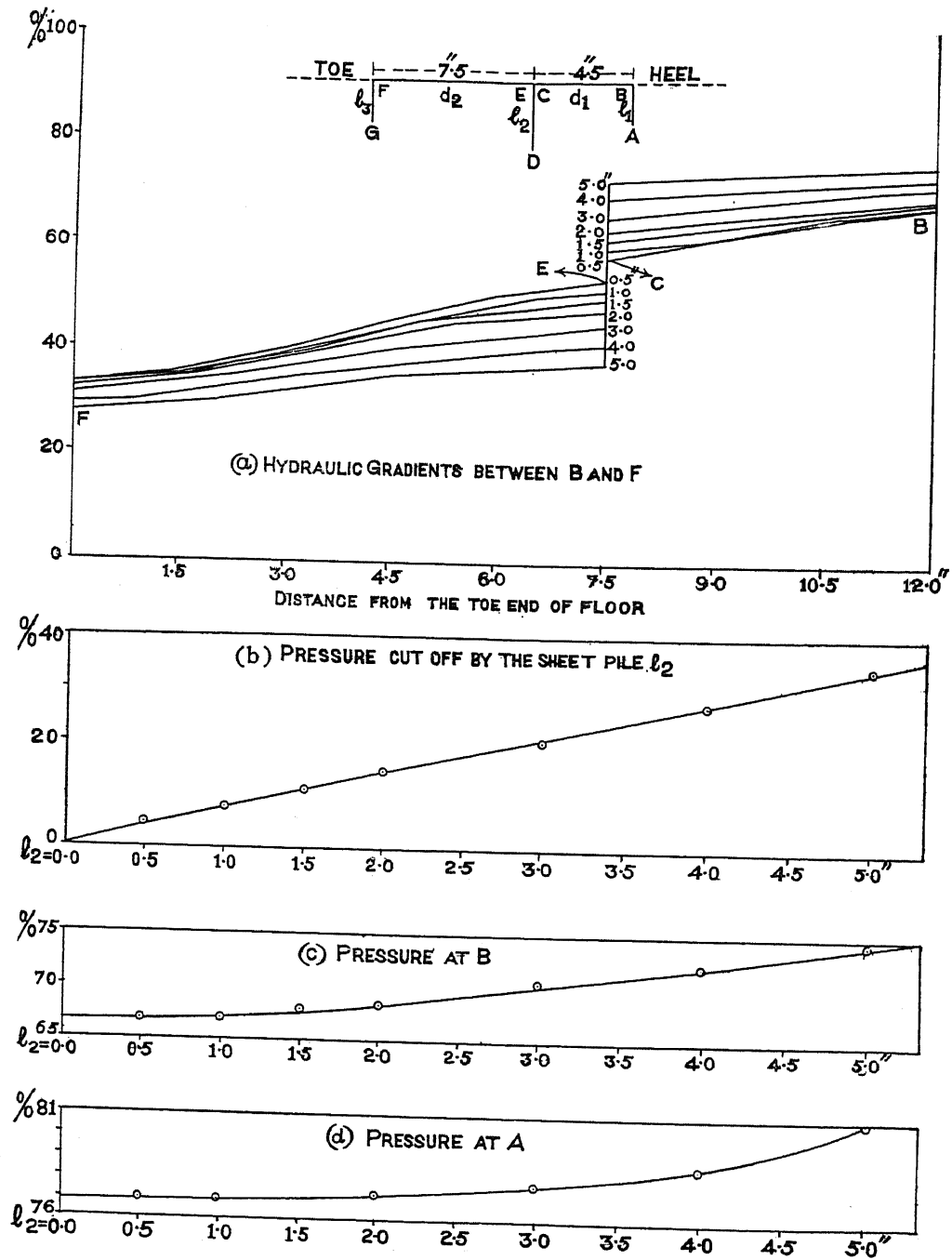


FIG. 4.

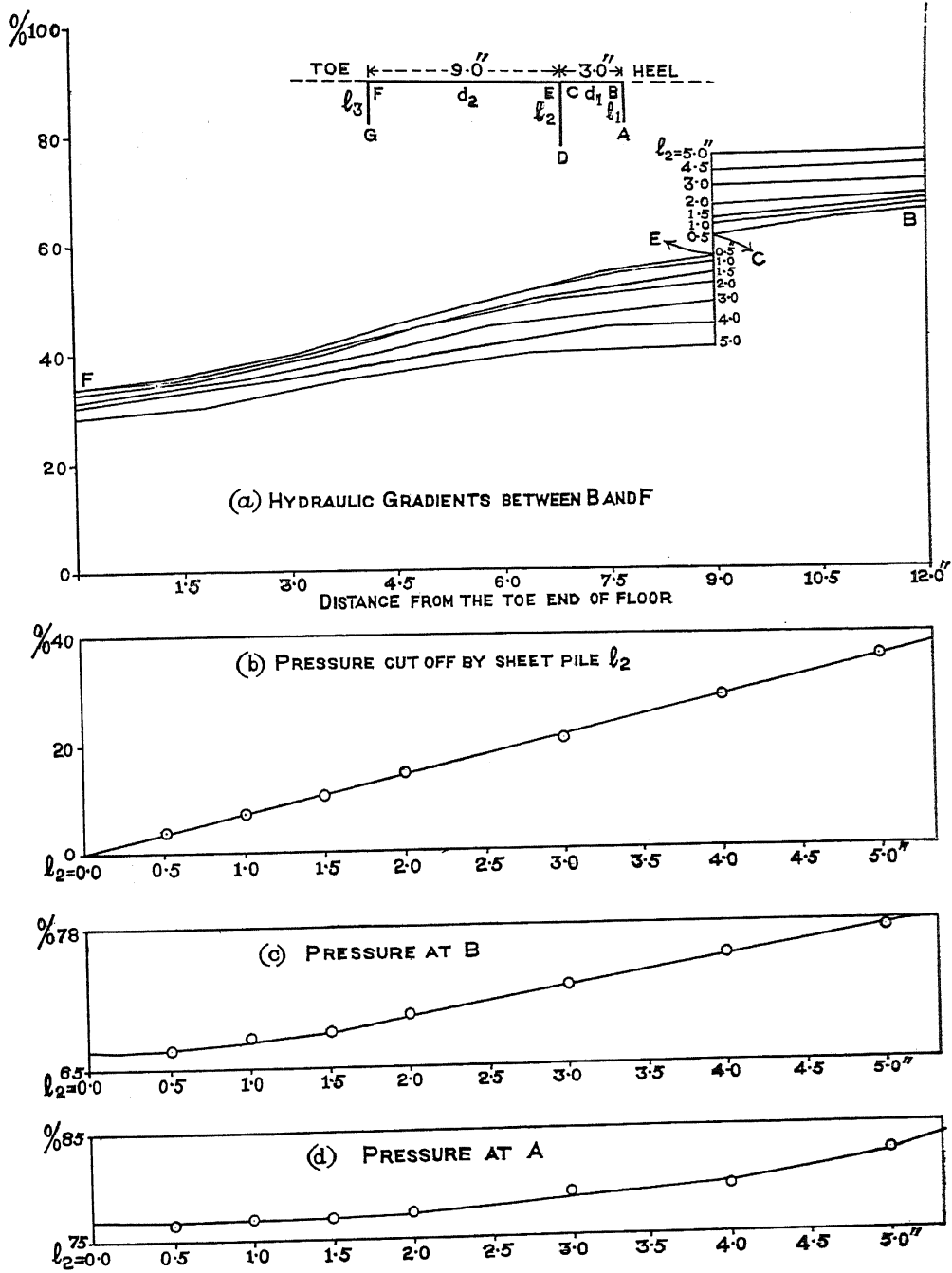


FIG. 5.

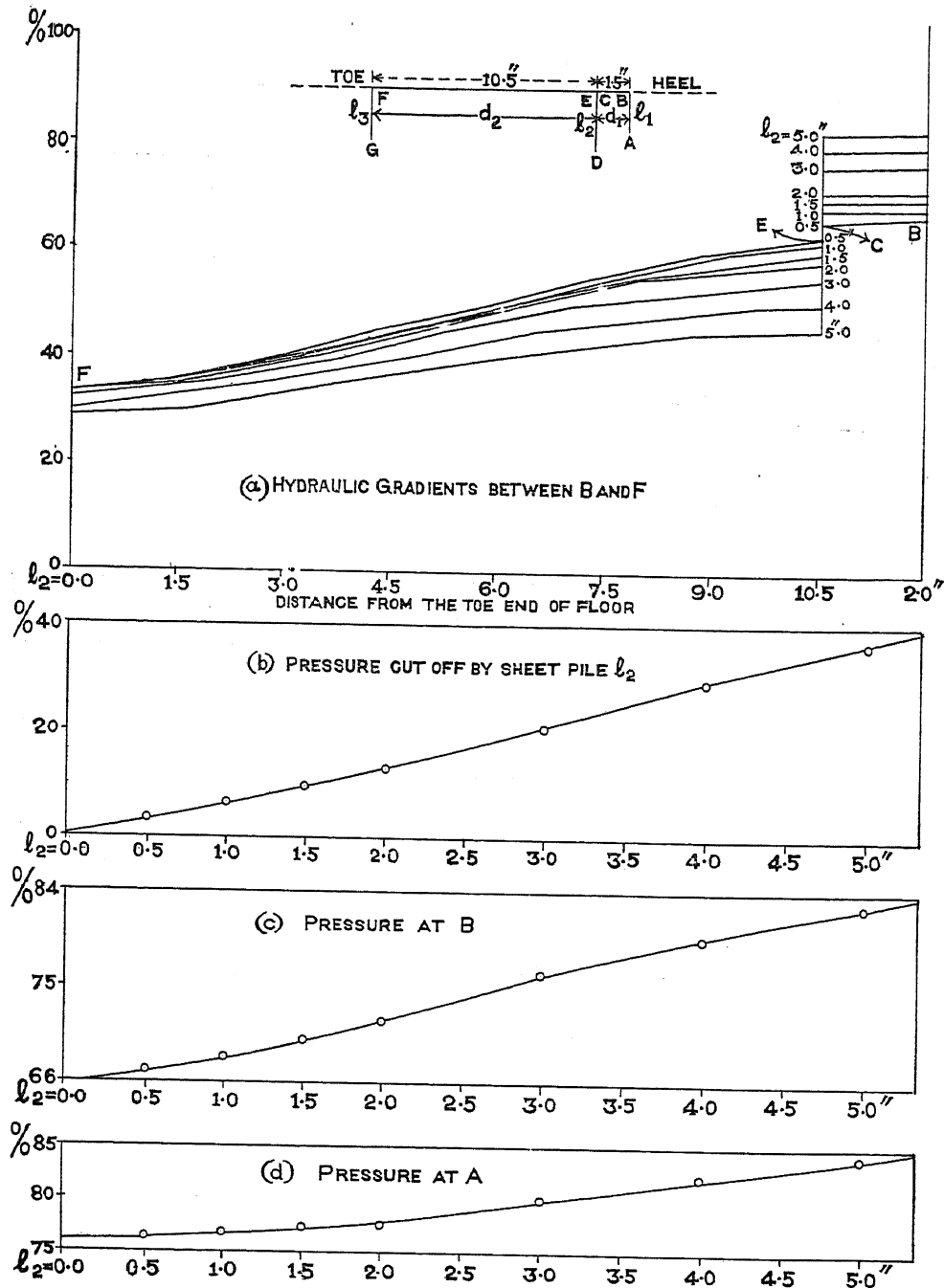


FIG. 6.

Taking the case of Fig. 3, it will be seen that the intermediate sheet pile l_2 is fixed half way between the heel and the toe sheet piles. The difference of head acting at the heel and the toe is represented by 100. The distribution of pressure along the floor and sheet piles under the weir is shown for the case of $l_2 = 0.5''$ by the curve B C E F in Fig. 3(a). The other curves in the figure are similarly plotted for the lengths 1.0'', 1.5'', 2.0'', 3.0'', 4.0'' and 5.0'' of the sheet pile.

The portions of the above curve such as E C along the ordinate show the pressures cut off by the intermediate sheet pile when its length is increased from 0'' to 5.0''. This variation of pressure with respect to its length is plotted in Fig. 3(b) which thus gives the law of variation of pressure in relation to the length of the intermediate sheet pile.

Figs. 3(c) and 3(d) show the variation of pressure at the points B and A (Fig. 1) respectively, when the length of l_2 changes from 0'' to 5.0''.

As will be seen from Fig. 3(c) the slope of the curve is small to begin with, but shows an increase when the length of the intermediate sheet pile exceeds 2'' in the model, *i.e.*, exceeds the length of the sheet piles at the two ends of the floor. This means that when the intermediate pile is longer than the piles at the end, it becomes more effective in reducing pressure than when its length is smaller than that of either of the piles at the end.

Fig. 3(d) shows the variation of the pressure at A when the length of the intermediate sheet pile increases gradually from 0'' to 5.0''. The variation of the pressures at A is similar in nature to that at B. As mentioned above the slope of the curve is small to begin with, but increases when the length of the intermediate pile exceeds 2'' in the model.

Figs. 4, 5 and 6 show in a similar way the hydraulic gradients for cases in which the intermediate sheet pile is 4.5'', 3.0'' and 1.5'' respectively from the sheet pile at the heel.

So far as the changes of pressures at B and A are concerned, the effects appear to be of a similar nature to that in Fig. 3 when the position of the intermediate sheet pile is changed as in Figs. 4, 5 and 6.

The pressure cut off by the intermediate pile itself, when its length and position are changed is shown in Table V.

It will be seen from Table V, that when the length of the intermediate pile l_2 is two inches or less, the pressure cut off by it decreases gradually when it is moved from the centre towards the heel sheet pile. On the other hand, when l_2 is longer than 2.0'' the pressure cut off by it increases gradually when it is shifted from the centre towards the sheet pile at the heel. It may be noted that the heel and the toe sheet piles are two inches in all these cases.

TABLE V.

Distance of the intermediate sheet pile from the toe end	Percentage pressure cut off by l_2						
	$l_2 = 0.5''$	1.0''	1.5''	2.0''	3.0''	4.0''	5.0''
6.0''	4.5	7.8	11.7	15.2	20.0	27.3	32.5
7.5	4.2	7.7	10.8	14.6	20.3	27.6	34.2
9.0	3.9	7.1	10.2	14.3	20.6	28.2	35.3
10.5	3.3	6.4	9.8	13.0	21.3	29.2	36.5

Thus in designing a weir, if the intermediate sheet pile is of about the same length as the end sheet piles or is shorter, it should be placed as near the centre as possible if it is to exert its maximum effect in reducing pressure. On the contrary if it is longer than the end sheet pile, it should be placed nearer to the heel sheet pile, for producing maximum effect in reducing pressure.

Design of a Weir with Three Sheet Piles.—The twentyeight cases investigated here are such as to cover the ordinary designs, so that in many cases one or the other set will be found to readily fit in with the design in question. In cases where it does not, the results obtained in the investigation can be applied to determine the uplift pressures under any weir with three sheet piles.

For example, let us take a weir with the following dimensions and determine the uplift pressures employing the graphs and tables given in the paper :

- Length of floor (L) = 150 ft.
- Length of sheet piles at heel and toe (l_1 and l_3) = 18 ft.
- Length of the intermediate sheet pile .. = 25 ft.
- Distance between the heel and the intermediate sheet pile = 50 ft.

Since the Law of Similarity holds good in models, the projection of the model to any prototype will yield identical results of uplift pressures. The dimensions of the prototype can thus be reduced for purposes of calculation to those shown in Fig. 7. The scale of reduction in this case is 1/150.

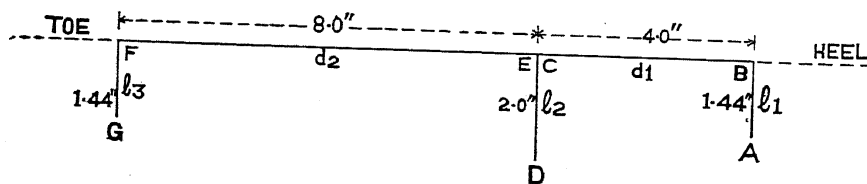


FIG. 7.

Referring to Fig. 7 and to Table II, it will be seen that the pressure at G varies from 22.8 to 22.1 when the length of the intermediate sheet pile changes from 0 to 3.0". This change being small, the effect of the central sheet pile on the variations of pressures at F and G may be considered negligible in practical cases. So far as the pressures at G and F are concerned, this reduces, therefore, to the case of two sheet piles at the ends of a floor. These pressures are 21.5 and 30.4 at G and F respectively.*

To find the pressure at E, the following method may be adopted:—

It will be seen from Table I that when the sheet pile l_2 is 2" long and is fixed exactly in the centre of the floor, the pressure at E is 42.3 per cent. The pressure at E increases as the intermediate sheet pile is shifted towards the heel end. The values of pressures at E for $d_2 = 7.5"$, $9.0"$ and $10.5"$ are found from Tables II, III and IV to be 47.7, 53.1 and 58.5 per cent. respectively. By interpolation the value of pressure at E when l_2 is 8.0" from the toe is found to be 49.5 per cent. The pressures at D and C, similarly obtained, are 56.8 and 63.8 per cent. respectively.

The determination of pressures at B and A offers some difficulty, as the influence of the intermediate sheet pile l_2 which is near the heel-pile has to be taken into account. If the sheet pile l_2 were removed altogether, the pressures at B and A would be 69.6 and 78.5 per cent. respectively as has been shown from the simple case of two equal sheet piles (1.44") at the ends of a 12" floor.⁴

The dimensions of the two sheet piles l_2 and l_1 in question are 2.0" and 1.44" respectively. The case corresponds to that of the sheet piles l_2 and l_1 equal to 2.8" and 2.0" respectively which has been investigated, the ratio of l_2 to l_1 in both cases being the same.

By plotting suitable curves from the Tables I-IV, the following values of pressures at A and B can be obtained when $l_1 = 2.0"$, $l_2 = 2.8"$ and $d_2 = 8.0"$. The pressures thus obtained at A and B are:—

	A.	B.
$l_2 = 0.0"$..	76.1	66.2
$l_2 = 2.8"$..	77.7	70.3

These values give the change in pressures at A and B when a 2.8" sheet pile is introduced at a point 8.0" from the toe.

It has already been observed that the pressures at A and B are 78.5 and 69.6 per cent. respectively when $l_1 = 1.44"$ and there is no intermediate

* These pressures have been read off from the curves in Fig. 2 of the paper on "Uplift Pressure and Design of Weirs with Two Sheet Piles", *Proceedings of the Indian Academy of Sciences*, 1936, Vol. IV, p. 147.

sheet pile. These values would increase in the ratios 77.7/76.1 and 70.3/66.2 respectively when a 2" sheet pile is introduced at 8.0" from the toe end. The values thus obtained are 80.2 and 73.9 per cent. respectively.

In order to verify the results obtained by the graphical method described above, a model of this design was tested experimentally in the electrical tray. The results obtained by the two methods are given below for comparison :

	A	B	C	D	E	F	G
Experimental Method ..	79.9	71.9	64.9	56.4	47.9	28.8	20.8
Graphical Method ..	80.2	73.9	63.8	56.8	49.5	30.4	21.5

It can be seen from the foregoing discussion that though the graphical method of obtaining the uplift pressures under the floor is not rigorous, it leads to results within two per cent. of the experimental value. In the design of actual works, this accuracy is quite sufficient, as there are other factors causing variations in uplift pressures which cannot be determined to this degree of accuracy.

When a doubt arises as to the correctness of the design by the graphical method or by other empirical equations derived from the graphs, it can be referred to experiment which can be carried out in a laboratory.

Summary.

In this investigation, the uplift pressures under weirs with three sheet piles have been determined. By studying the effect of varying the length and position of the intermediate sheet pile, working rules have been obtained for the design of weirs with three sheet piles.

We have great pleasure in thanking Dr. E. McKenzie Taylor, the Director, for the keen interest he took in this problem.

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