PAPER No. 190

ELECTRICAL METHOD FOR DETERMINING PRESSURE DISTRIBUTION UNDER HYDRAULIC WORKS.

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Introduction.

In a series of investigations, ([1], [2]) carried out in the Irrigation Research Institute, Lahore, it was definitely established that the distribution of uplift pressure under hydraulic works follows the same law as the distribution of potentials in conductors. Once this was established, it became possible to employ the method for the study of uplift pressure under weirs. A number of standard cases, such as (*i*) flush floors with a sheet pile, (*ii*) depressed floors with a sheet pile, (*iii*) floors with different depressions, and (*iv*) floors with two sheet-piles, have been investigated, ([3], [4]) by this method.

In the present paper, it is proposed to give the results of investigation on a few actual cases of weirs. In addition to this, the results of investigations on single sheet-piles without upstream or downstream apron are also included. These results form part of a systematic investigation on the subject that is being carried out in the Institute.

Results.

The pressure contours and the hydraulic gradients along the works are shown in the figures.

(1) *Haveli Project, Trimmu Weir.*—The uplift pressure distribution under the Trimmu weir is shown in Fig. 1. This figure gives the results for the originally proposed design where the inverted filter, *ef*, is supposed to be in action.

It sometimes happens that the inverted filter gets blocked and hence the pressure distribution no longer remains the same as when the filter is in action. The Trimmu weir with a blocked filter has been investigated and the results are shown in Fig. 2.

The above two cases were for the original design. Experiments in the hydraulic laboratory of the Irrigation Research Institute, Lahore,

showed that shifting of the upstream sheet-pile by a length of 45 feet towards the crest pile, *i.e.*, from position *b* to position *d*, does not affect the uplift pressure materially. This design was, therefore, investigated by the electrical method. The results are represented in Fig. 3.

A third design, without the crest sheet-pile, was investigated. The results for this design are also shown in Fig. 3*.

The central sheet-pile under the works takes off nearly 15% of the total pressure difference between the upstream and the downstream. Without the central sheet-pile, this 15% will be distributed along the floor.

Since only the uplift pressures are investigated in this paper, it is not proposed to discuss the design here.

(2) *Inlet at R. D.* 87,040 *L. C. C. East Circle.*—Three designs of this were investigated.

The results are given below.

Fig. 4 gives the distribution of uplift pressure for the case when the sheet-pile at *a* is 15 ft. and that at *b*, 7.5 ft. deep.

The distribution shown in Fig. 5, is for the case in which sheet-pile at *a* is 15 ft. and that at *b* is 5.5 ft.

In Fig. 6 is shown the distribution of uplift pressure for this inlet when the sheet-pile at *a* is 15 ft. deep, but there is no sheet-pile at *b*.

(3) *Proposed Kalabagh Weir*, 1935.—The uplift pressure distribution under this design of the Kalabagh weir is shown in Fig. 7. Only one design was investigated; this had three sheet piles, the downstream pile 15 ft., the crest pile 30 ft., and the upstream pile 10 ft.

(4) *Merala Weir.*—In Fig. 8 is shown the distribution of uplift pressure under Merala weir. Only one design was investigated, having 30 ft. and 18 ft. for the upstream and downstream piles.

Single Sheet-piles, without the upstream or the downstream aprons.—As mentioned in the introduction, the following standard cases were investigated.

Fig. 9 gives the case where the upstream and the downstream surfaces of the porous strata are at the same level.

Figures 10 to 16 give the uplift pressure distribution for single sheet-piles, without the upstream or the downstream aprons, but with

*The method of designing the weirs, taking into account the uplift pressure exit gradient, etc., has already been discussed in the official reports of the Irrigation Research Institute, Lahore.

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the upstream and the downstream at different levels. The ratios $\frac{l_2}{l_1}$, as shown in the figures, were 0, $\frac{1}{2}$, 1, 2, 3, 4, 5.

Fig. 17 shows the variation of pressure at the end A of the sheet-pile for different values of $\frac{l_2}{l_1}$. It is clear from this figure that the sheet-pile is most effective when the ratio $\frac{l_2}{l_1}$ is less than 1. The nature of the curve indicates the decrease in efficiency of the pile in cutting off pressure, when this ratio is increased.

Table I gives the values of pressure at the end of sheet pile for various values of $\frac{l_2}{l_1}$ and Table II gives the pressure at the end of sheet-pile for various values of $\frac{l_2}{l_2+l_1}$.

Summary.

Distribution of uplift pressure under different forms of designs of Trimmu weir, Inlet at R. D. 87,040, L.C.C. East Circle, Kalabagh weir and Merala weir has been investigated. The pressure contours and the hydraulic gradients are given in the diagrams.

Cases of single sheet-piles, without the upstream and the downstream apron, have also been investigated. The law of variation of pressure at the end of a sheet-pile and its efficiency in cutting off pressure with different ratios of $\frac{l_2}{l_1}$ is given diagrammatically and in tabular forms.

Our thanks are due to Dr. E. McKenzie Taylor for his keen interest in the problem. Our thanks are also due to the Engineers who gave us the benefit of their advice, when these cases were under investigation.

TABLE I.

Values of Pressure at A for various values of l_2/l_1.

* $\frac{l_2}{l_1}$	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.0	0.0	18.1	30.5	36.1	38.5	40.1	41.4	42.3	43.1	43.7
1.0	44.1	44.4	44.7	44.9	45.1	45.3	45.5	45.7	45.9	46.1
2.0	46.3	46.4	46.6	46.7	46.9	47.0	47.1	47.2	47.3	47.4
3.0	47.5	47.6	47.7	47.8	47.8	47.9	47.9	47.9	48.0	48.0
4.0	48.1	48.1	48.1	48.2	48.2	48.2	48.3	48.3	48.3	48.3
5.0	48.4	..	..	..	..	..	..	..	..	..

* The vertical line below l_2/l_1 reads the first integeral figure and the horizontal line reads to the first place of decimals.

TABLE II.

Values of Pressure at A for various values of l_2/l_1+l_2.

† $\frac{l_2}{l_1+l_2}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.00	0.0	2.1	4.1	6.1	8.1	10.1	12.1	14.1	16.0	17.9
.10	19.8	21.6	23.3	24.9	26.5	27.9	29.1	30.3	31.4	32.4
.20	33.3	34.1	34.9	35.6	36.2	36.8	37.3	37.8	38.2	38.7
.30	39.1	39.4	39.8	40.1	40.5	40.8	41.1	41.4	41.6	41.9
.40	42.1	42.3	42.5	42.8	43.0	43.2	43.4	43.6	43.8	44.0
.50	44.1	44.3	44.5	44.6	44.8	45.0	45.1	45.3	45.4	45.6
.60	45.7	45.8	46.0	46.1	46.2	46.4	46.5	46.6	46.8	46.9
.70	47.1	47.2	47.3	47.4	47.5	47.6	47.7	47.8	47.9	48.0
.80	48.1	..	..	..	..	..	..	..	..	..

† The vertical line below l_2/l_1+l_2 reads the first place of decimals and the horizontal reads the second place.

TABLE I.

Values of Pressure at A for various values of l_2/l_1.

* $\frac{l_2}{l_1}$	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
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1.0	44.1	44.4	44.7	44.9	45.1	45.3	45.5	45.7	45.9	46.1
2.0	46.3	46.4	46.6	46.7	46.9	47.0	47.1	47.2	47.3	47.4
3.0	47.5	47.6	47.7	47.8	47.8	47.9	47.9	47.9	48.0	48.0
4.0	48.1	48.1	48.1	48.2	48.2	48.2	48.3	48.3	48.3	48.3
5.0	48.4	..	..	..	..	..	..	..	..	..

* The vertical line below l_2/l_1 reads the first integeral figure and the horizontal line reads to the first place of decimals.

TABLE II.

Values of Pressure at A for various values of l_2/l_1+l_2.

† $\frac{l_2}{l_1+l_2}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.00	0.0	2.1	4.1	6.1	8.1	10.1	12.1	14.1	16.0	17.9
.10	19.8	21.6	23.3	24.9	26.5	27.9	29.1	30.3	31.4	32.4
.20	33.3	34.1	34.9	35.6	36.2	36.8	37.3	37.8	38.2	38.7
.30	39.1	39.4	39.8	40.1	40.5	40.8	41.1	41.4	41.6	41.9
.40	42.1	42.3	42.5	42.8	43.0	43.2	43.4	43.6	43.8	44.0
.50	44.1	44.3	44.5	44.6	44.8	45.0	45.1	45.3	45.4	45.6
.60	45.7	45.8	46.0	46.1	46.2	46.4	46.5	46.6	46.8	46.9
.70	47.1	47.2	47.3	47.4	47.5	47.6	47.7	47.8	47.9	48.0
.80	48.1	..	..	..	..	..	..	..	..	..

† The vertical line below l_2/l_1+l_2 reads the first place of decimals and the horizontal reads the second place.

REFERENCES.

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(3) V. I. Vaidhianathan, M.A., D. Sc., F. Inst. P., Gurdas Ram. M.Sc., & E. Mckenzie Taylor, M.B.E., Ph. D., D. Sc. — *Proceedings of the Indian Academy of Sciences*. (In print.)

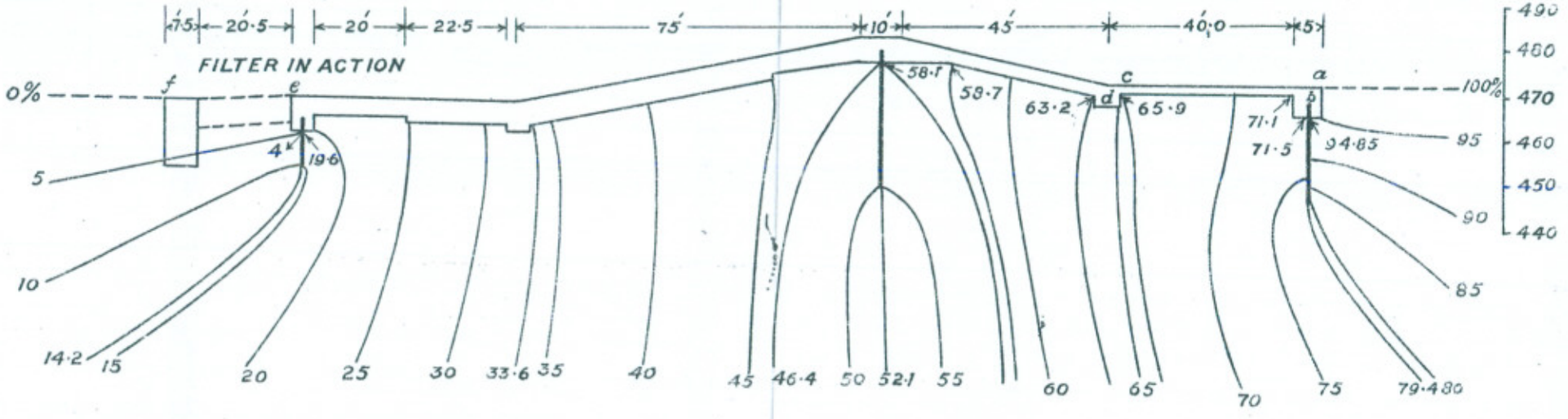
(4) V.I. Vaidhianathan, M.A., D.Sc. F. Inst. P., Gurdas Ram, M. Sc. & E. Mckenzie Taylor, M.B. E., Ph.D., D.Sc. — *Research Publication, Irrigation Research Institute, Lahore, Pun ab*, Vol. V, No. 6.

FIG 1

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HAVELI PROJECT

TRIMMU WEIR



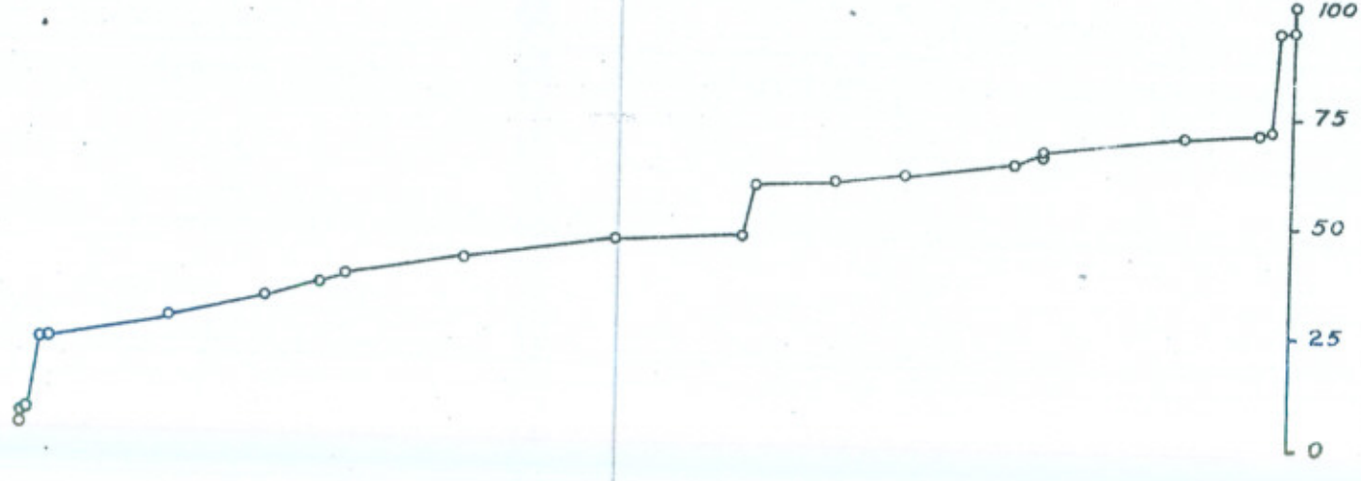
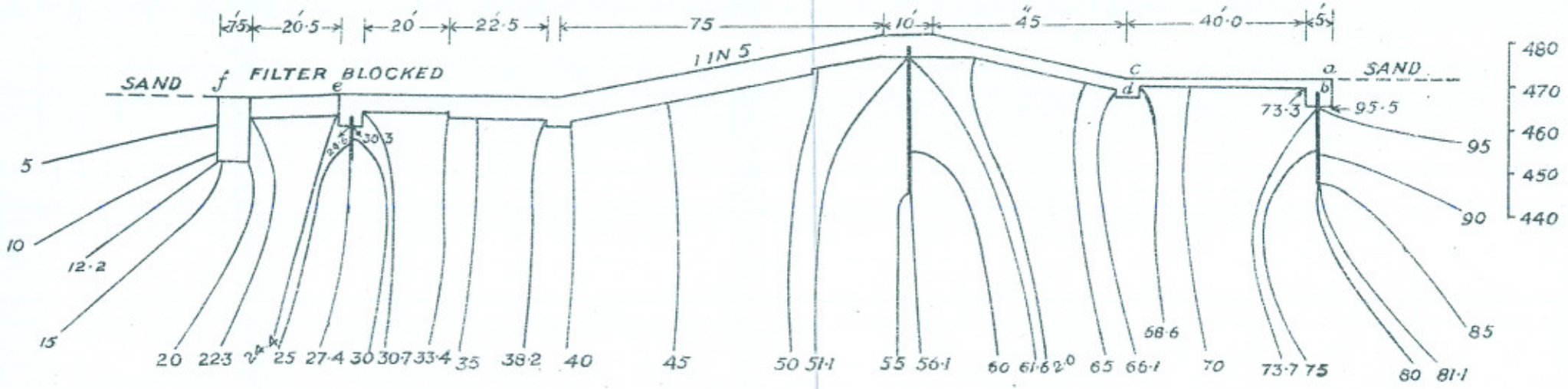


FIG 2

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HAVELI PROJECT
TRIMMU WEIR



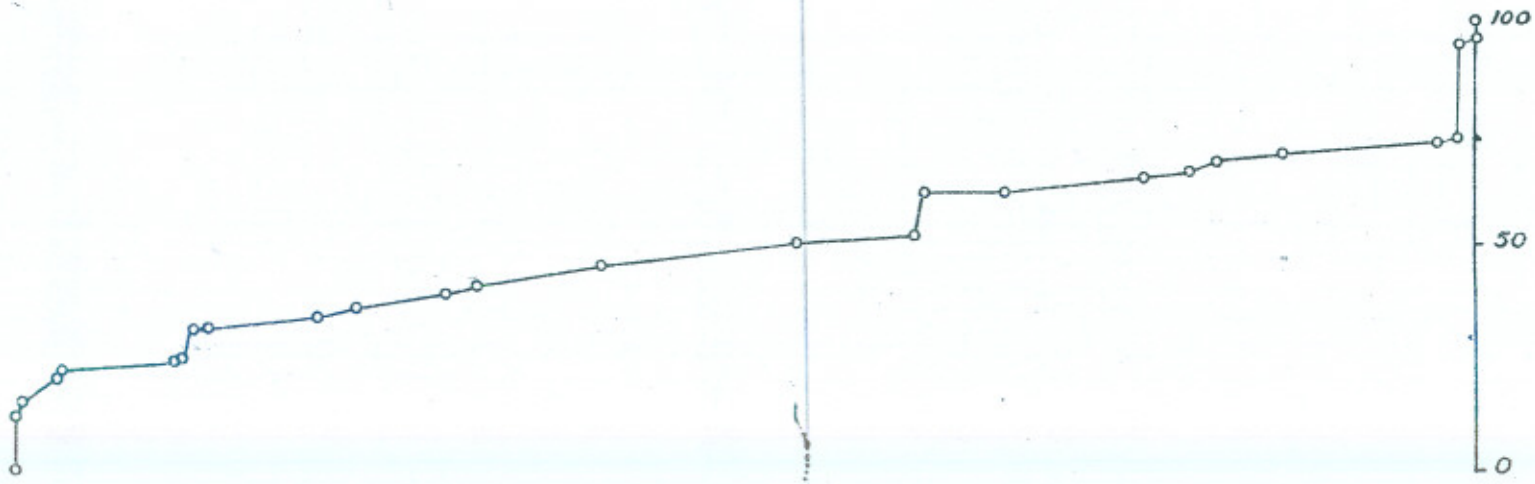
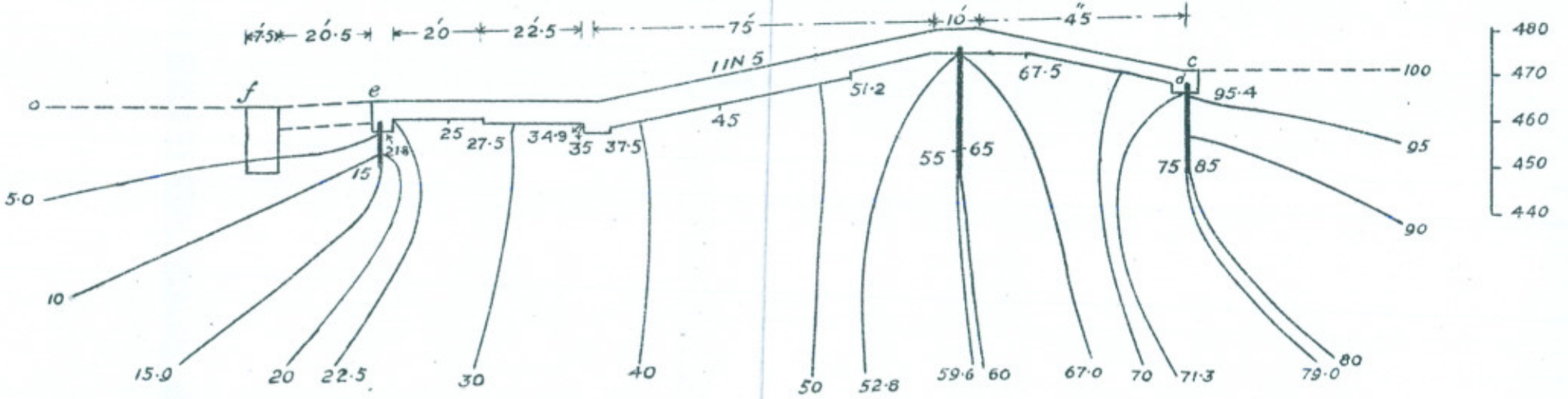


FIG.3

HAVELI PROJECT

TRIMMU WEIR

(WITH CREST PILE)



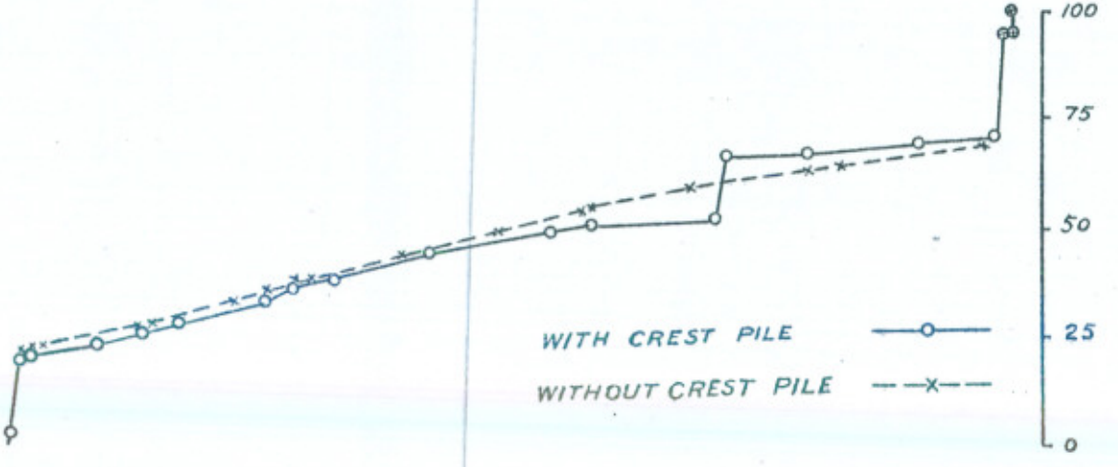
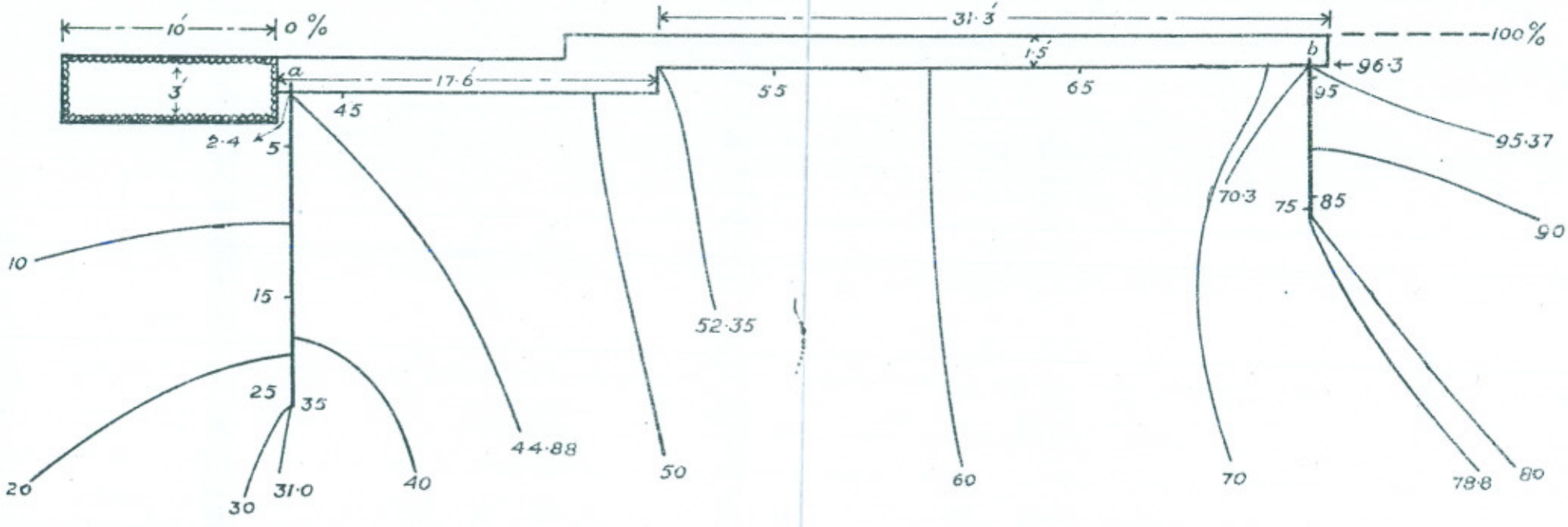


FIG 4
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L.C.C. EAST CIRCLE
INLET AT R.D. 87040.



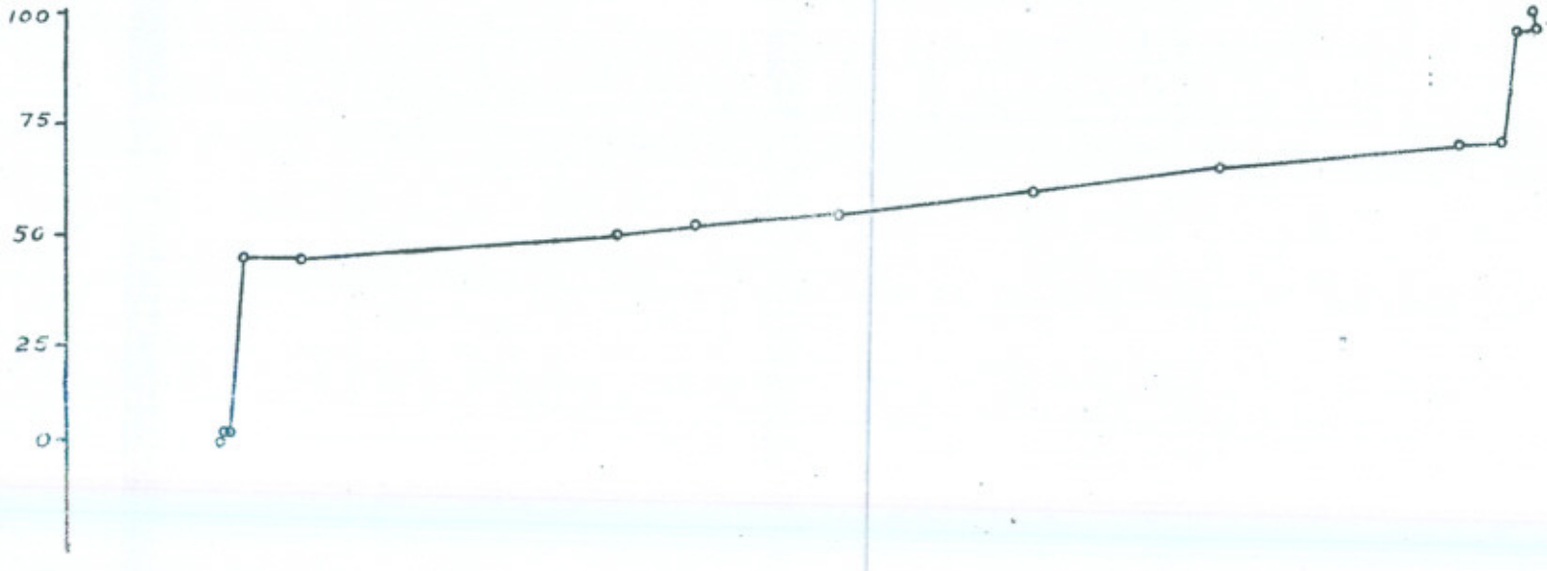
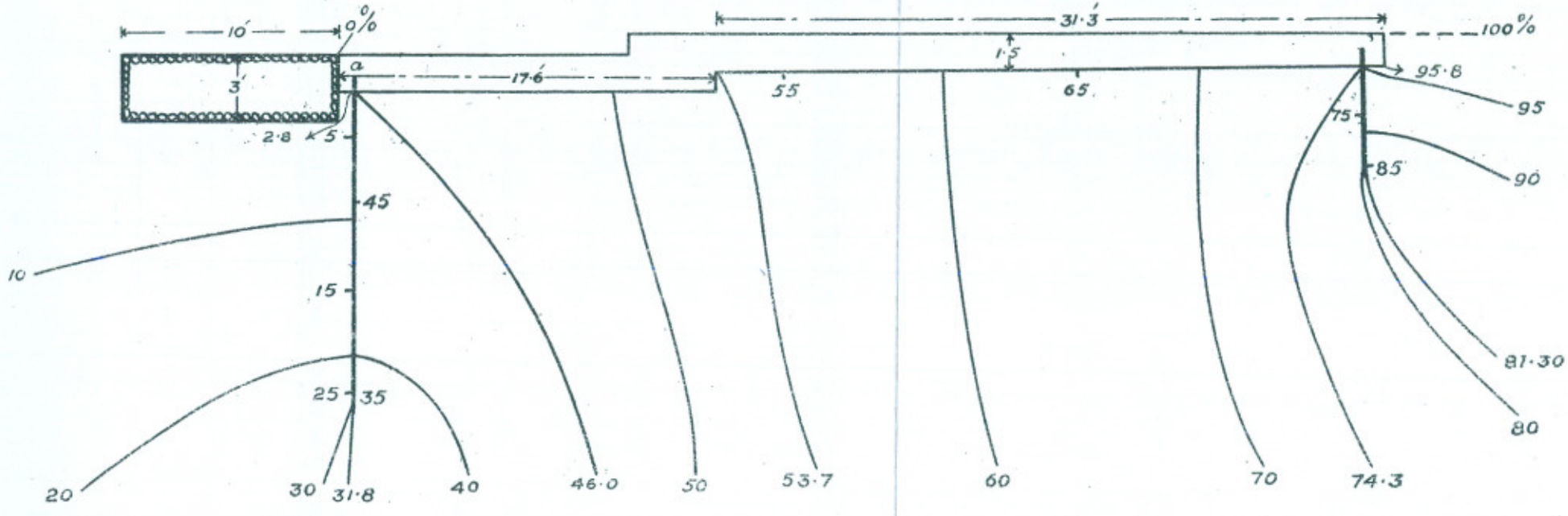


FIG. 5
19°
L.C.C. EAST CIRCLE
INLET AT R.D.87040



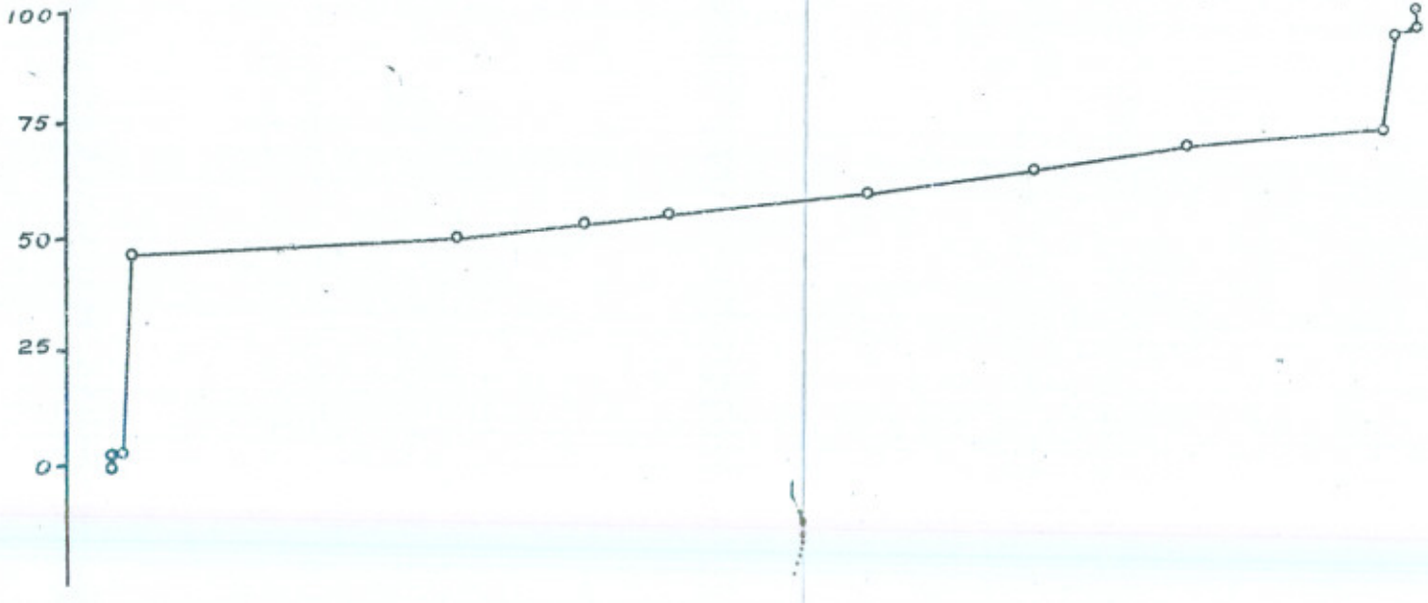


FIG. 6

L.C.C. EAST CIRCLE

INLET AT R.D. 87040

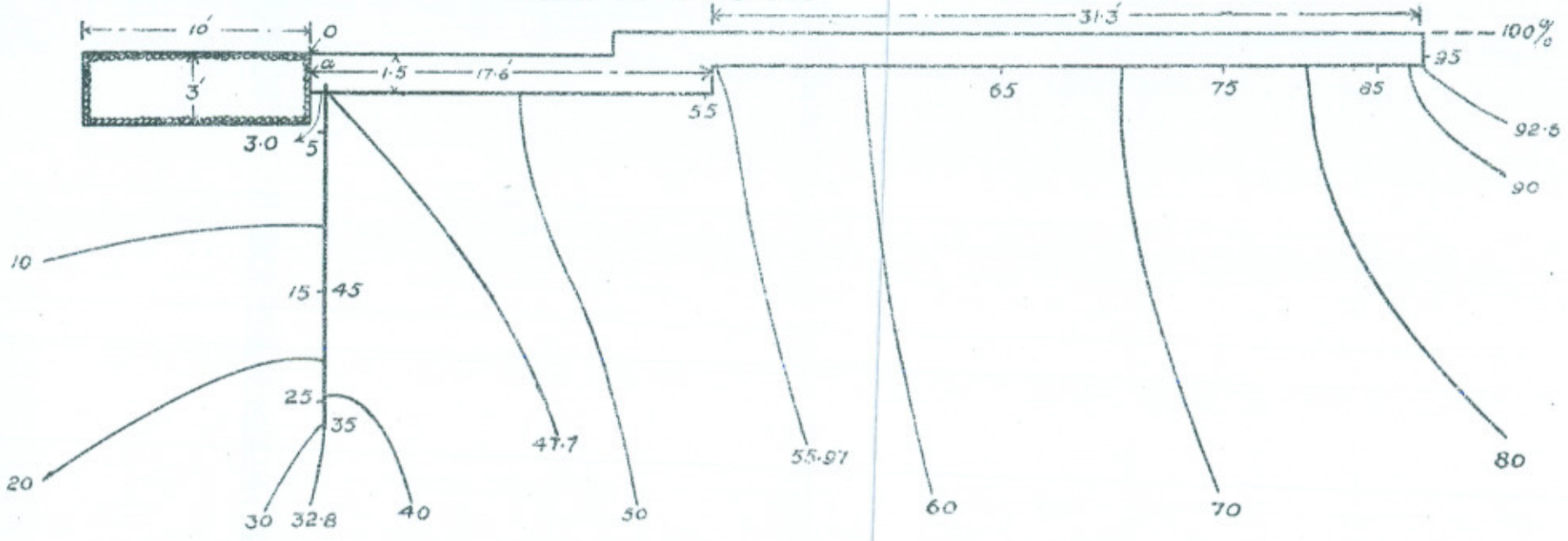




FIG. 7
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KALABAGH WEIR

SCALE = 1/200.

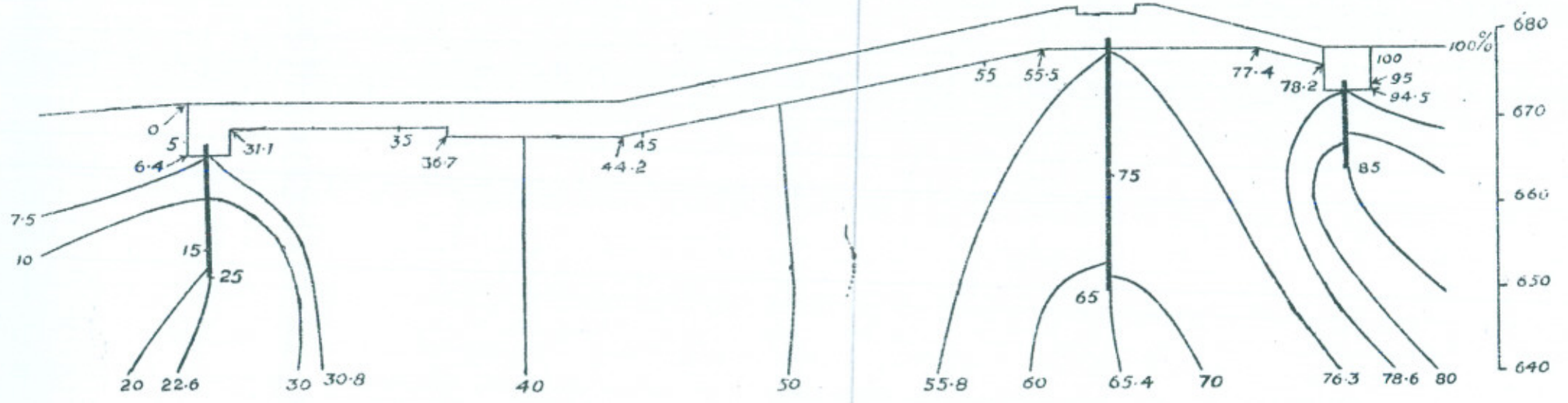


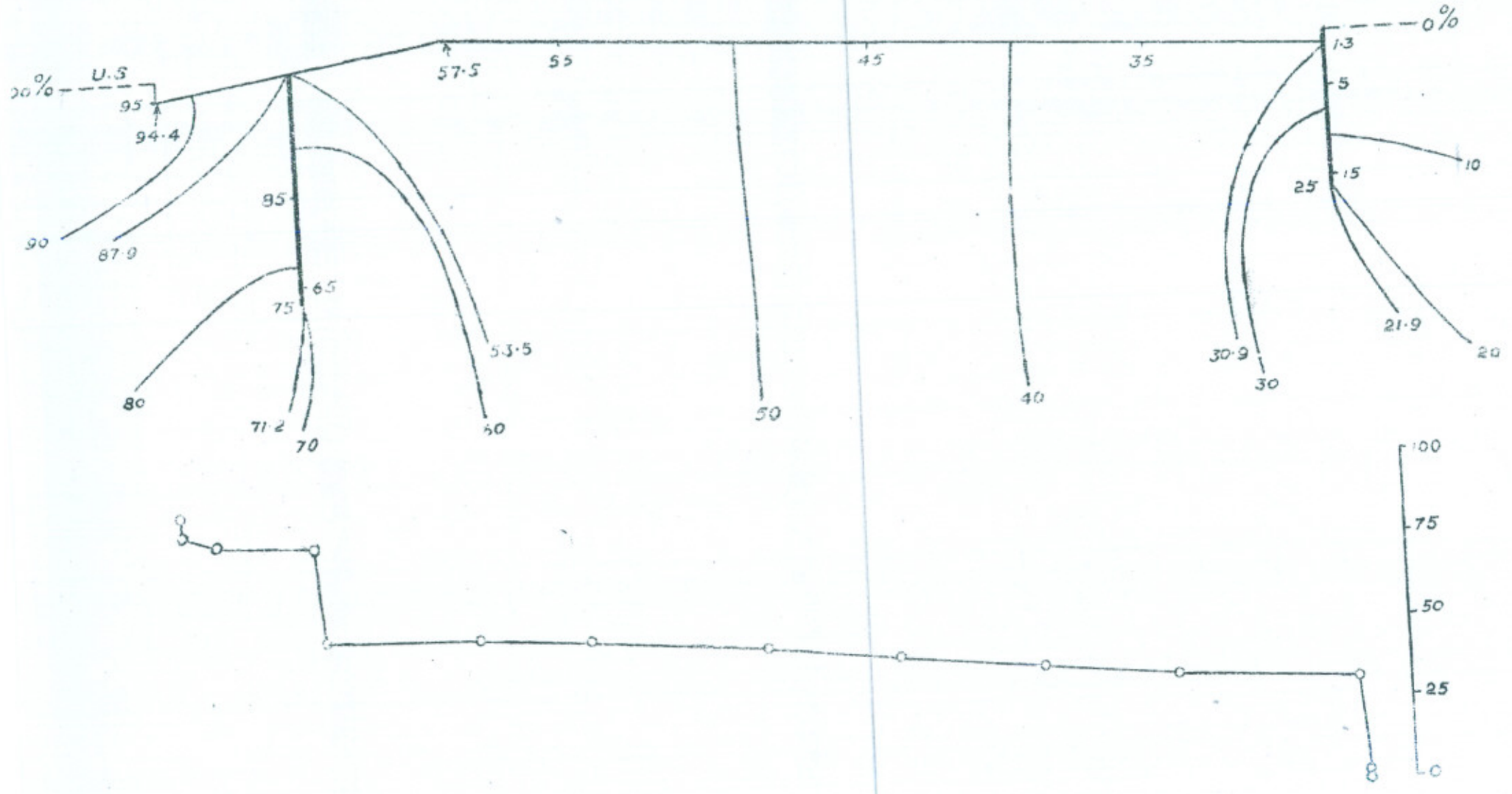


FIG. 8

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MARALA WEIR

SCALE = 1/200



SHEET-PILES WITHOUT FLOOR

FIG 9

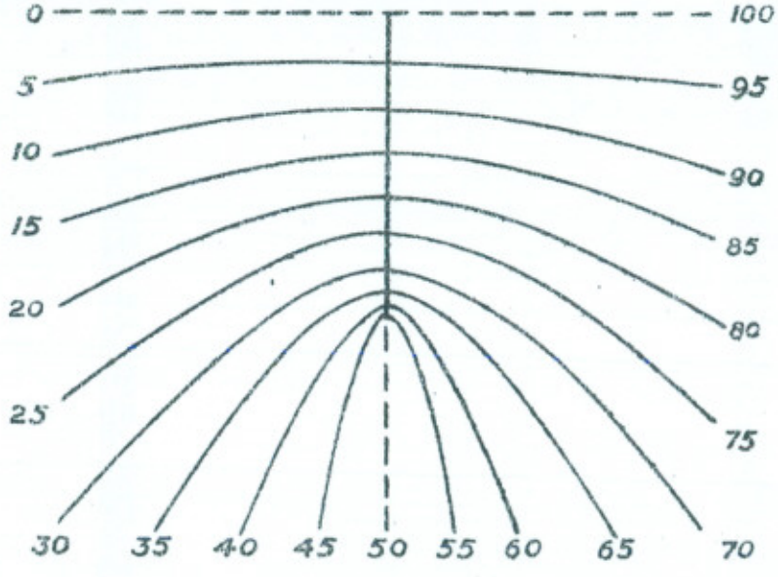


FIG 10

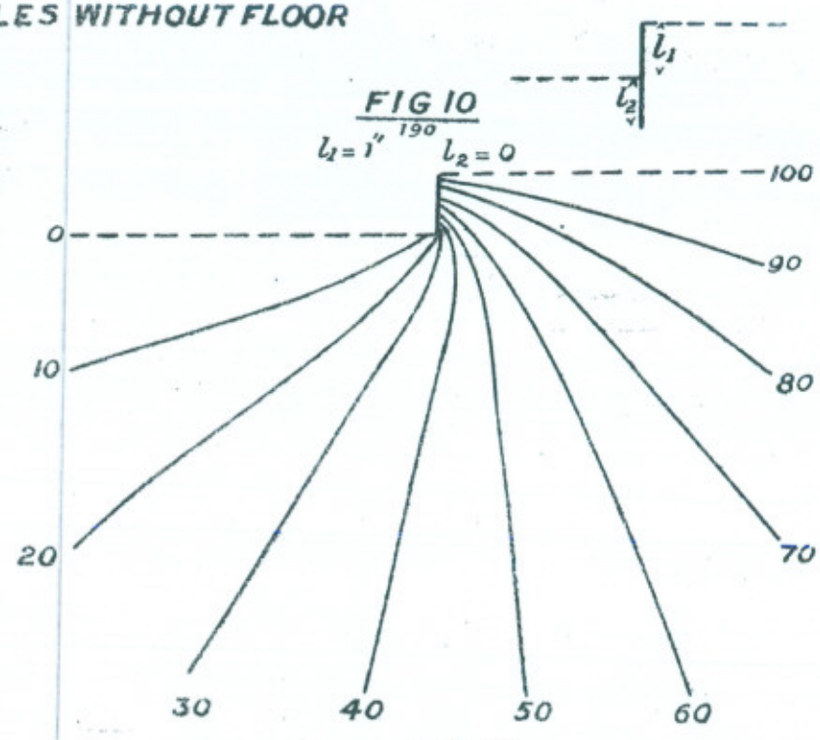


FIG 11

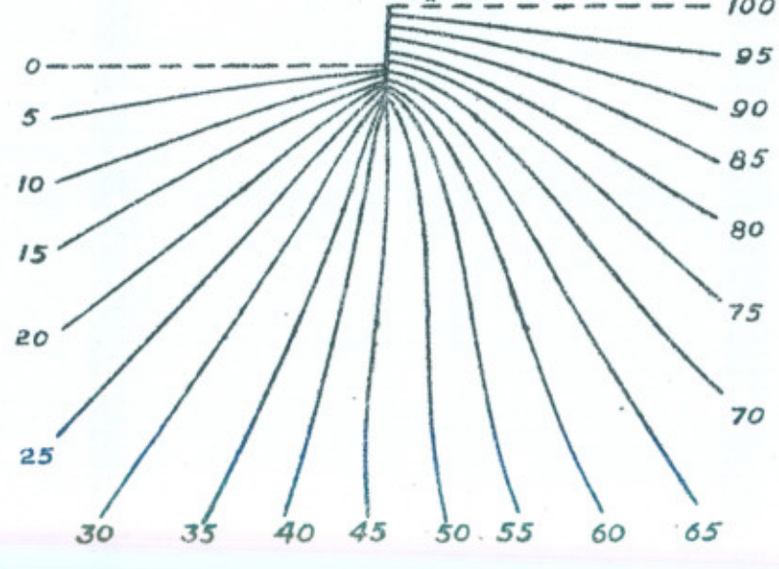
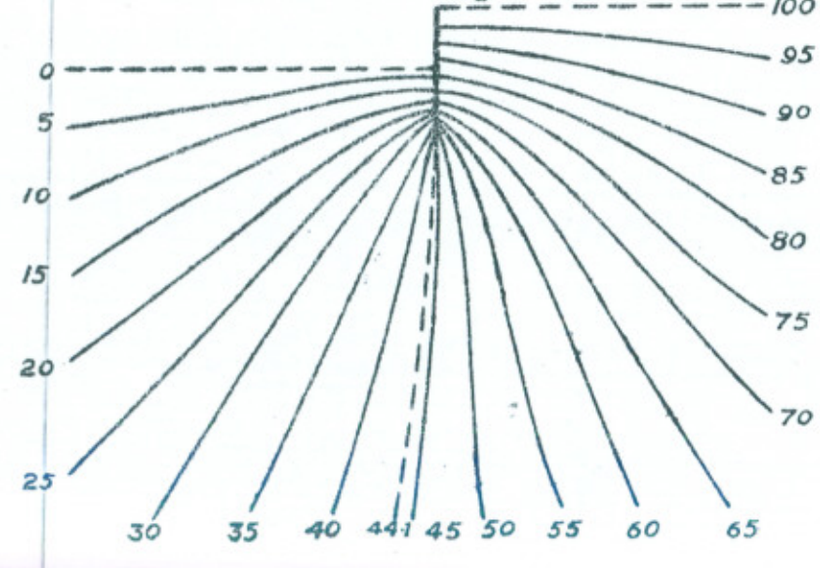


FIG 12



SHEET PILES WITHOUT FLOOR

FIG 13

$l_1 = 1''$ $l_2 = 2''$

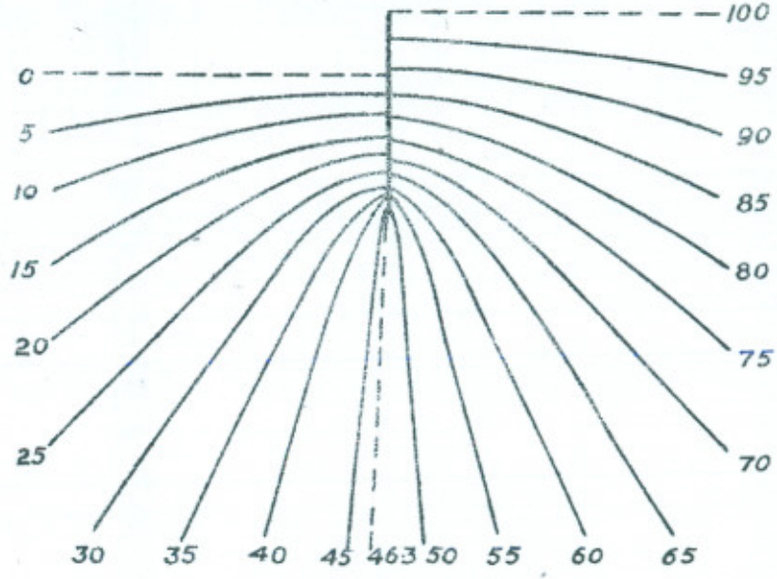


FIG 14

$l_1 = 1''$ $l_2 = 3''$

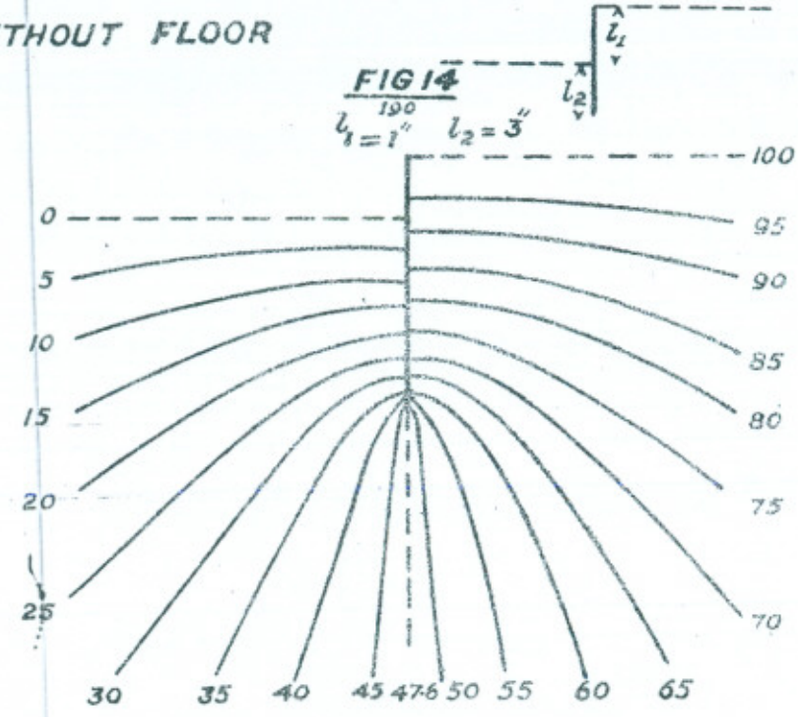


FIG 15

$l_1 = 1''$ $l_2 = 4''$

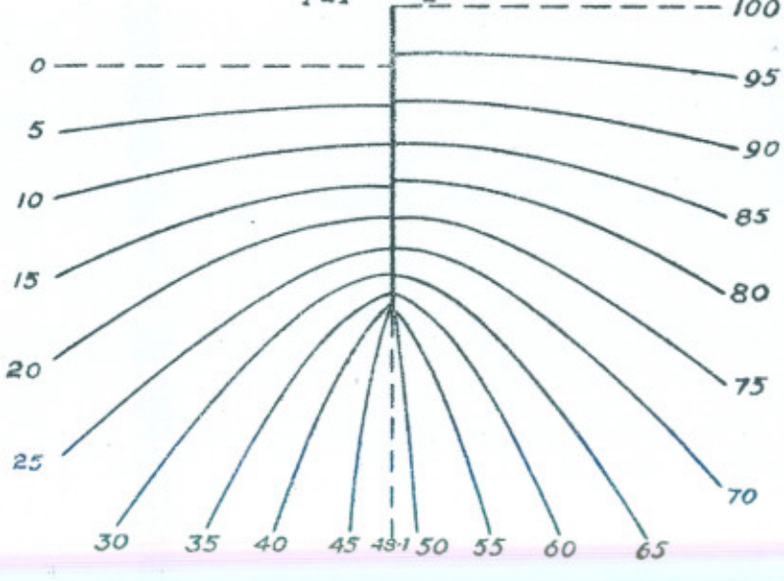


FIG 16

$l_1 = 1''$ $l_2 = 5''$

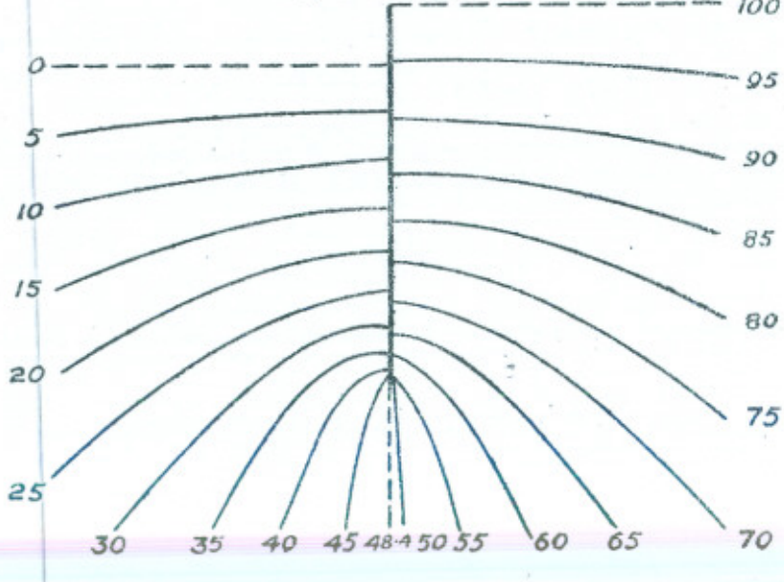
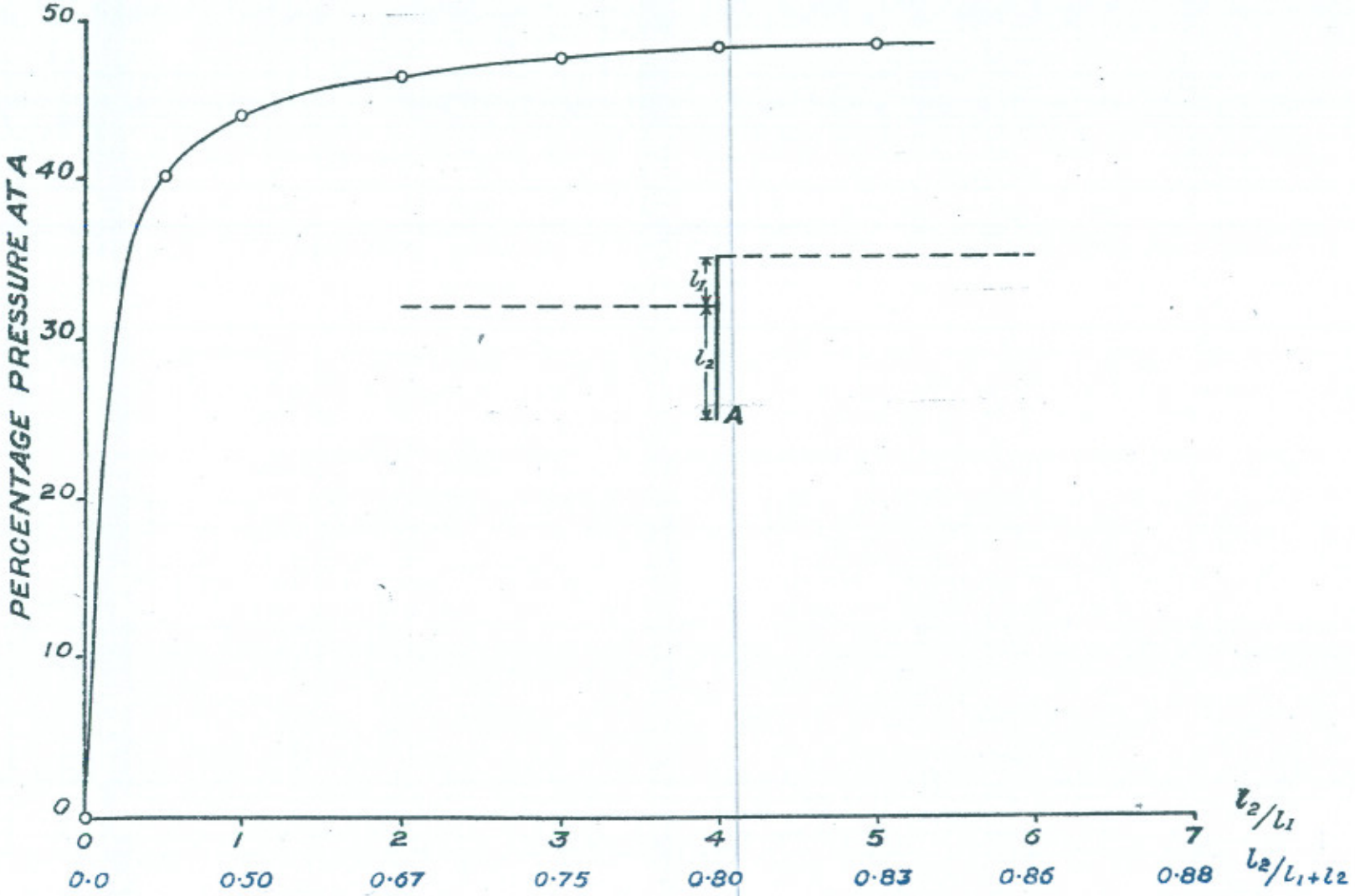
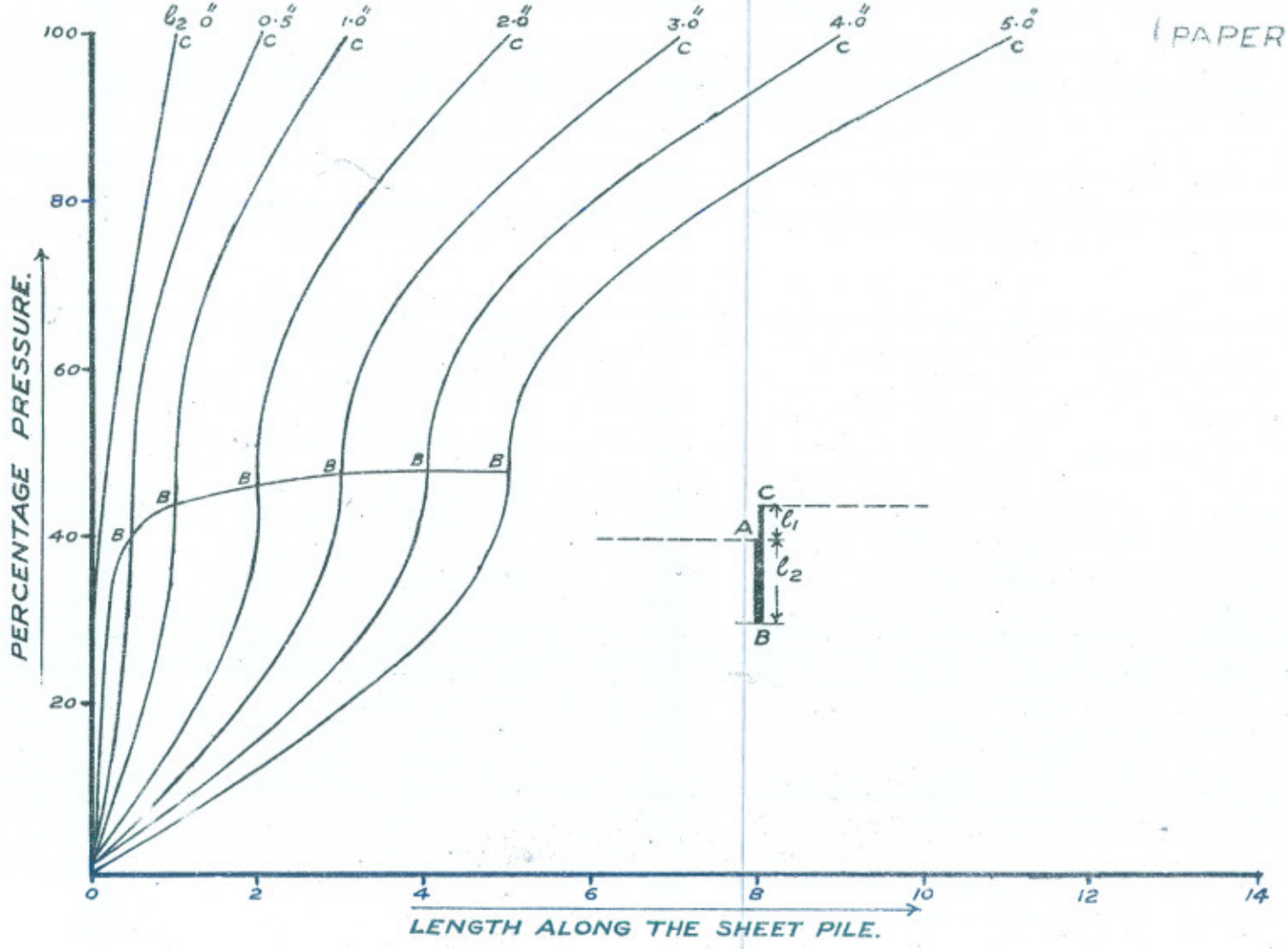


FIG.17

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PRESSURE AT THE END OF SHEET PILES WITHOUT FLOOR




l_2 0"
0·5"
1·0"
2·0"
3·0"
4·0"
5·0"
C
B
100
80
60
40
20
PERCENTAGE PRESSURE.
0
2
4
6
8
10
12
14
LENGTH ALONG THE SHEET PILE.
A
l_1
l_2

DISCUSSION.

Dr. **V. I. Vaidhianathan**, introducing the paper said that an electrical method had been employed to investigate the uplift pressure on models of weirs. The results presented in the paper were only a small part of a series of investigations that were being conducted in the Institute. A number of standard cases had been worked out and working rules had been obtained for most of the ordinary combinations. The results by the electrical method were tested with those in direct models and the prototypes. The results agreed remarkably well. It might not be out of place to suggest that in this method the authors had discovered a quick and accurate means of determining the pressure distribution under the engineering works of enormous magnitude, (*i.e.*) the weirs on the head-works.

In the paper, they had only given the pressure at the end of the sheet-piles in the last set of diagrams. The actual pressure distributions along the sheet-piles were shown in the accompanying figure.

Mr. **Kanwar Sain** congratulated the authors on the clever scientific device to which attention had been drawn in the paper. The device itself had been previously described in the Proceedings of the Indian Academy of Sciences in July 1935 and in the paper now presented to the Punjab Engineering Congress only results of a few models of some of the existing and the proposed weirs as determined by the electrical method had been given.

When the speaker saw the method in the institute for the first time, he was struck with the simplicity of the apparatus and the speed with which the uplift pressure could be determined on any proposed combination of sheet-piles and impervious floors. It did not require more than a few hours to get the results.

When the authors had plotted the curves for all the various combinations and permutations that might occur in practice, it was hoped that the whole information would be published in one handy volume for the engineer's ready reference.

The pressure as indicated for the Trimmu Weir in Figure I appeared to him somewhat confusing. He presumed that the percentage of the pressure at various points as given by the authors were in the plane of the down-stream minimum water level and not at the bottom of the floors as the figure would indicate. He requested the authors to state the effect of the sloping floor on the pressures, if any.

Mr. **A.N. Khosala** stated that the electrical method of determining uplift pressure under works was first developed by Pavlovsky about 1920 But this failed to inspire confidence as the results from the electric model did not agree even remotely with those on the field structures. These variations were due to variations in silt deposits upstream and

downstream of the structures, variations in temperature of inflowing and sub-soil water and unknown geological formations of the sub-soil. The reproduction of the Panjnad results on the hydraulic and electrical model with very close agreement, established for the first time the value of the model work.

The electric model work was quick and accurate. The hydraulic model work was comparatively slow, and though capable of as high a degree of accuracy as the electric model, was apt to be generally less accurate in actual practice. This, however, had a wider range of usefulness as it would reproduce subsoil movements and damage. It had also greater demonstrative value.

Dr. Vaidhianathan had developed the technique of the electrical model to a high degree of precision. This paper included only a part of the standard forms suggested by the speaker on which Dr. Vaidhianathan and Mr. Gurdas Ram had worked; when the entire set would be completed, very useful data would be available for the latter designs. This work of the authors would be of the utmost importance to the profession.

Dr. Vaidhianathan thanked those who took part in the discussion. The points which called for an answer were mainly : (1) the effect of the inclination of the floor on the pressure. This point had not yet been investigated ; (2) regarding a comprehensive paper on this subject, he wished to say that this was surely in the minds of the authors. But they were working on the various problems and after the completion of the work a paper would be published, which they believed would contain all that was essential. But for those in the Punjab, any complicated problem could be experimentally solved within a day's time in the Institute.