PAPER No. 185.

PRESSURES UNDER A MODEL OF PANJNAD WEIR AND UNDER THE PROTOTYPE

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In the discussion following the publication of experiments carried out on models,[1] engineers laid stress on the necessity for proving that the results obtained were comparable with those actually recorded on the prototype before models could be accepted as a basis of design. Few structures on sand foundations have the necessary equipment of pressure pipes to enable conditions in a prototype to be studied, and advantage has been taken of the pressure observations recorded by Khosla on Panjnad weir, and presented in his paper to the Punjab Engineering Congress, 1933.[2] In the discussion of Khosla's paper, Mr. Hadow, Chief Engineer, suggested that findings on Panjnad weir might be tested out on a scale model. The present paper is an account of observations made on a model of Panjnad weir to a scale of 1/50 in accordance with the suggestion. In addition to observing the pressures, the streamlines under the model were also traced as described previously.[3]

The model was placed in a tank 8 feet long, 3 feet deep, and 5 inches wide. The front of the tank consisted of glass through which the course of the stream lines could be observed and photographed. The back of the tank was made of steel plate and carried pressure observation points. These points were situated at positions with reference to the model similar to those occupied by the pressure pipes, which form the basis of Khosla's observations. The method of taking the pressure observations has been described elsewhere.[4] The arrangement of the model in the tank is shown in Diagram I.

The method of construction originally adopted has been modified considerably as a result of experience. Sheet piles are now made of a $\frac{3}{8}$" teak board with a brass plate on each side. These plates project $\frac{1}{2}$" beyond the wood and form grooves in which rubber tubes are inserted. The brass plates are $\frac{1}{4}$" narrower than the tank and the overall dimension of the pile is raised to $\frac{1}{8}$" more than the width of the tank by the rubber tubes. When the pile is inserted the rubber tubes form a water-tight seal with the front and back of the tank.

The piles are tested for water-tightness by filling in sand to about three inches above the bottom of the pile and applying a head of water.

The model is constructed by filling the tank with sand to about two inches above the final sand level and allowing to settle for two days.

After this time the top of the sand is formed to the required shape and cement poured in before the sand has had time to dry.

In the first series of experiments the observations were taken for various heads at approximately uniform temperature, the effect of silting upstream not being taken into consideration. The observations taken under these conditions will indicate the maximum pressure that may be experienced on the floor. An example of the results is shown in Table I.

If these results are compared with those of Khosla, it will be seen that the drop in pressure from the upstream end of the model to Pipe No. 31 is much greater in the prototype than it is in the model situated under the conditions already described. From this it must be inferred that there is some difference between the conditions upstream of the actual work and those upstream of the model.

In a more recent paper [5] by Khosla, he has laid stress on the possibility of deposits of silt upstream of the work, and of the temperature of the water affecting the observed pressures. Since the drop in pressure from the upstream end of the work to Pipe No. 31 was much greater on the work than that observed in the model, it was decided to investigate the effect of additions of silt to the surface of the sand upstream of the model. Silt was added to the water upstream of the model to give varying depths of silt deposits. The effects of these additions on the pressure under the work were determined, the results being recorded in Table II and Diagram II. From these tables it will be seen that as the depth of the silt deposit upstream of the work increases, the pressure lost between the upstream end of the work and Pipe No. 31 also increases.

For detailed comparison reliable pipes in the prototype were selected, and the results recorded in similarly situated pipes under the model are given for similar silt conditions upstream in Table III and in Diagram III. If Pipe No. 31 is selected as a standard for comparison between the model and the prototype, it will be seen that when the prototype reading at Pipe No. 31 is approximately the same as the reading on Pipe No. 31 in the model, then the pressures at the remaining corresponding pipes are also in excellent agreement, the difference generally not exceeding 2 per cent. From this it can be concluded that for similar positions of measuring points the model gives reliable indications as to the pressures that will be experienced on the work.

Further confirmation of the effect of silt was obtained by reversing the experiment. Silt was withdrawn from the upstream end of the work, so as to give observations corresponding to similar observations to those on the prototype. Finally the whole of the silt was withdrawn and the initial observations on the model with the original conditions were repeated. These observations are shown in Table IV. It will be seen from Table IV that as the silt deposit is reduced, the pressures on the work becomes greater, until finally with the removal of

whole of the deposit, the pressure obtained in the initial experiments are produced. That is to say that the seasonal variation of pressure observed at Panjnad can be reproduced fully by an alteration of the silt.

It has already been shown that the pressures on the model are higher when no silt is present upstream than when such a deposit occurs. It follows from this that if a work of the nature of Panjnad weir is designed from a model, then the worst conditions that may be experienced on the work have been provided for.

The observations recorded at Panjnad were taken between 15th May, 1932 and 30th November, 1932. Khosla has shown that the pressures are subject to a seasonal variation and has suggested two possible explanations, one of which has been shown by the model to be feasible. He has indicated that the pressure may vary either with the depth of the deposit of silt upstream of the weir or with variations in the temperature of water percolating through the sand under the weir.

In order to test the second factor, observations were made on the model for different temperatures of the water percolating through the sand. A reservoir of cold water was maintained at the upstream end of the tank, and a comparison of the pressures on the model was made when the upstream compartment was maintained at 24°C in one case and 15°C in the other case. A temperature gradient was established through the sand when the upstream compartment was maintained at 15°C. The results of the observations are shown in Table V and in diagram IV. It will be seen that the temperature gradient results in a distortion of the pressures and that the results are inconclusive so far as Khosla's suggestion is concerned.

After the pressure observations were completed, the water in the reservoir feeding the upstream compartment was replaced by a solution of 1 per cent. potassium chromate. Silver nitrate was run in from tap funnels at five points upstream of the model, and the stream lines traced. Diagram V shows the final state of the streamlines.

If the streamlines in the model are compared with those deduced by Khosla from his pressure data, it will be seen that there is a very good agreement.

The equi-pressure lines at Panjnad weir have been calculated by Dr. N. K. Bose. For comparison, the equi-pressure lines were also calculated for the model experiments. An example of the two sets of equi-pressure lines are shown in Diagram VI. It will be seen that there is a well-marked similarity between those derived from Khosla's results and those obtained by the model experiments.

Advantage may also be taken of the results which have been discussed to compare these with those obtained by Hebert[6] in his study of the hydraulic electric analogy. Hebert states, that "From a comparison of electric analogy results with actual measurements and model experiments the conclusion indicated at the present stage is that any application of analogy results to problems of practical design must be

made with care. I believe the analogy method has considerable value for a qualitative study of sub-soil flow. It is not possible yet to make much quantitative use of the method. There are still too many factors involving the geological conditions at any dam site which elude evaluation and so cannot be simulated in an analogy set up."

Since the results of the hydraulic electric analogy, the pressure observations on a model and the pressure observations on the prototype in the case of Panjnad weir are now available, it is possible to examine the statement of Hebert quoted above.

A comparison between the pressure percentages obtained from the model on sand with no silt and uniform temperature with those obtained from Hydraulic Electric Analogy discloses a very close agreement as the following figures show :—

Pipe No.	*Lahore Method.*	*Hydraulic Electric Analogy.*
34 ..	94·01 ..	95·0
35 ..	87·12 ..	86·5
36 ..	76·12 ..	76·5
33 ..	75·79 ..	75·00
32 ..	71·55 ..	71·00
31 ..	70·39 ..	70·5
30 ..	68·63 ..	67·3
29 ..	67·99 ..	66·3
28 ..	67·64 ..	66·7
27 ..	66·72 ..	66·25
24 ..	63·64 ..	64·00
25 ..	64·46 ..	62·50
26 ..	60·00 ..	59·20
23 ..	58·73 ..	58·3
22 ..	55·45 ..	55·0
21 ..	54·24 ..	53·8
18 ..	53·00 ..	54·2
19 ..	53·03 ..	53.1
20 ..	54·05 ..	54.7
17 ..	48·14 ..	47·8
16 ..	45·67 ..	45·8
13 ..	39·37 ..	40·7
14 ..	39·21 ..	40·5
15 ..	38·85 ..	39·4
10 ..	30·58 ..	31·0
11 ..	30·77 ..	30·5
12 ..	26·43 ..	27·5
9 ..	23·02 ..	23·0
8 ..	16·79 ..	14·5
7 ..	10·94 ..	8·0

The first important conclusion to be drawn from the above figures is that they afford definite evidence that the hydraulic electric analogy is correct and can be applied quantitatively to design. It has already been pointed out that a work designed as a result of experiments on a model will withstand the worst conditions that may be experienced. Since the study of the model by the hydraulic electric analogy method gives almost identical results with the Lahore method, a work designed on the hydraulic electric analogy will be safe also under the worst conditions.

A second important conclusion to be drawn from the agreement in the above figure is that the flow in the sub-soil can be examined mathematically. Any deviation between pressure observations on the prototype and on the model can be explained by the effect of silt and can be assessed as percentages of the standard percentage pressures at each point in the sub-soil.

The more complicated profiles cannot be dealt with mathematically. It seems that instead of attempting to arrive at a mathematical solution of any problem either the method adopted in Lahore or the hydraulic electric analogy will give a quick and complete solution of the most complicated forms of foundation profiles of weirs.

A further important point resulting from the agreement between the two methods of investigation of the model is that, providing the material under a work is uniform in character, the grade of the material used in the model study is of little importance. This simplifies considerably the application of model results to the design of a work when the geological conditions are known. It also indicates the importance of a thorough study of the geological conditions at a proposed site for a work since any abnormalities in the material under the work may be reflected in the pressures experienced.

Summary and Conclusions.

1. The pressures under a model of Panjnad weir have been investigated.

2. It has been shown that the pressures recorded on the model can be brought to agree with those observed on the prototype.

3. When no silt is present upstream of the model, the pressures observed are much higher than those experienced on the prototype except probably in its initial stages of operation. It follows, therefore, that a work designed from a model situated on pure sand will be safe against uplift under the worst conditions that may be expected on the prototype.

4. The seasonal variations in pressure noticed by Khosla have been investigated. It has been shown that the major portion of these variations can be reproduced on the model by varying the depth of silt upstream.

5. The close agreement between the results obtained on the prototype and those on the model by the Lahore method and the Hydraulic Electric Analogy under standard conditions of flow show that the hydraulic electric analogy may be used also for the study of models of proposed works.

References.

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5. A. N. Khosla .. "A Note on the Location and Erection of Pressure Pipes and on the Standard Method of Observation and Record of Pressures under Works on Permeable Foundations." (Submitted to the Central Board of Irrigation.)
6. Herbert, D. J. .. "Hydrostatic Uplift Pressures under Dams on Pervious Earth Foundations." (United States Department of Interior Bureau of Reclamation. Technical Memorandum No, 384.)

TABLE I.

Pressure Observations on a Model of Panjnad Weir.

Head 8.964 cm. No Silt Upstream.

Pipe No.	Observed Pressure.	Correction.	Actual Pressure.	Head	Percentage effective Pressure.
Mean		.254			
U.S.L.	79.845	.248	79.594	9.744	100.00
34	79.270	.260	79.010	9.160	94.01
35	78.570	.231	78.339	8.489	87.12
36	77.515	.239	77.276	7.426	76.21
33	77.455	.220	77.235	7.385	75.79
32	77.065	.243	76.822	6.972	71.55
31	**76.960**	**.251**	**76.709**	**6.859**	**70.39**
30	76.785	.248	76.537	6.687	68.63
29	76.715	.240	76.475	6.625	67.99
28	76.675	.234	76.441	6.591	67.64
27	76.600	.249	76.351	6.501	66.72
24	76.300	.249	76.051	6.201	63.64
25	76.355	.224	76.131	6.281	64.46
26	75.950	.254	75.696	5.846	60.00
23	75.825	.252	75.573	5.723	58.73
22	75.490	.237	75.253	5.403	55.45
21	75.380	.245	75.135	5.285	54.24
18	75.280	.266	75.014	5.164	53.00
19	75.270	.253	75.107	5.167	53.03
20	75.390	.273	75.117	5.267	54.05
17	74.785	.244	74.541	4.691	48.14
16	74.565	.265	74.300	4.450	45.67
13	73.965	.279	37.686	3.836	39.37
14	73.935	.264	73.671	3.821	39.21
15	73.875	.239	73.636	3.786	38.85
10	73.080	.250	72.830	2.980	30.58
11	73.100	.252	72.848	2.998	30.77
12	72.665	.240	72.425	2.575	26.43
9	72.240	.247	72.093	2.243	23.02
8	71.760	.274	71.486	1.636	16.79
7	71.170	.254	70.916	1.066	10.94
Mean D.S.L.	70.105	.252 .258	69.850		

TABLE II.

SHOWING THE EFFECT OF ADDITION OF SILT UPSTREAM OF THE MODEL ON

ıe No.	Head 8.201 Actual Pressure.	Depth of silt.—Nil %Effective Pressure.	Head 10.259 Actual Pressure.	Depth of silt=3/8" %Effective Pressure.	Head 9.179 Actual Pressure.	Depth of silt.—½" %Effective Pressure.	Head 8.321 Actual Pressure.	Depth of silt.—5/8" %Effective Pressure.	Head 12.136 Actual Pressure.	Depth of silt.—5/8" %Effective Pressure.	Head 10.717 Actual Pressure.	Depth of silt. 7/8" %Effective Pressure.	Head 7.486 Actual Pressure.	Depth of silt.—¾" %Effective Pressure.	Head 11.967 Actual Pressures.	Depth of silt.—1" %Effective Pressure.
an S. L.	79.594	..	80.126	..	78.927	..	77.604	..	80.494	..	80.557	..	77.209	..	81.842	..
34	79.010	94.01	77.985	79.12	76.290	71.27	74.945	68.04	77.610	76.24	76.455	61.72	74.240	60.34	76.840	58.20
35	78.339	87.12	77.379	73.21	75.869	66.68	74.654	64.55	76.539	67.41	75.989	57.38	73.919	56.05	76.424	54.73
36	77.276	76.21	77.766	67.24	75.186	59.24	74.061	57.42	75.176	56.18	75.311	51.05	73.451	49.80	75.656	48.31
33	77.235	75.79	76.645	66.06	75.185	59.23	74.020	56.93	75.230	56.63	75.290	50.85	73.455	49.85	75.630	48.09
32	76.822	71.55	76.197	61.69	74.877	55.88	73.752	53.71	74.787	52.97	74.912	47.33	73.267	47.34	75.307	45.39
31	**76.709**	**70.39**	**76.069**	**60.44**	**74.859**	**55.68**	**73.744**	**53.61**	**74.739**	**52.58**	**74.934**	**47.53**	**73.234**	**46.90**	**75.289**	**45.24**
30	76.537	68.63	76.042	60.18	74.652	53.43	73.577	51.60	74.302	48.98	74.672	45.09	73.067	44.67	75.087	43.55
29	76.475	67.99	75.855	58.36	74.600	52.86	73.490	50.56	74.355	49.42	74.680	45.16	73.045	44.38	74.985	42.70
28	76.441	67.64	75.856	58.37	74.616	53.03	73.506	50.75	74.376	49.59	74.701	45.36	73.036	44.26	74.996	42.79
27	76.351	66.72	75.351	53.45	73.546	41.38	73.461	50.21	74.261	48.64	74.631	44.70	72.976	43.45	74.936	42.29
24	76.051	63.64	75.596	55.83	74.336	49.98	73.326	48.59	74.121	47.49	74.446	42.98	72.916	42.65	74.746	40.70
25	76.131	64.46	75.551	55.40	74.361	50.26	73.321	48.53	74.086	47.20	74.421	42.75	72.896	42.39	74.776	40.95
26	75.696	60.00	75.106	51.06	74.031	46.66	73.056	45.34	73.671	43.78	74.121	39.95	72.681	39.51	74.436	38.11
23	75.573	58.73	76.973	49.76	73.938	45.65	72.988	44.53	73.533	42.64	74.043	39.22	72.633	38.87	74.348	37.38
22	75.253	55.45	74.678	46.89	73.718	43.25	72.788	42.12	73.263	40.42	73.843	37.35	72.523	37.40	74.133	35.58
21	75.135	54.24	74.355	43.74	73.600	41.97	72.705	41.12	73.070	38.83	73.725	36.25	72.435	36.23	74.000	34.47
18	75.014	53.00	74.419	44.36	73.499	40.87	72.614	40.03	72.954	37.87	73.594	35.03	72.354	35.15	73.884	33.50
19	75.017	53.03	74.377	43.95	73.567	41.61	72.652	40.49	73.007	38.31	73.652	35.57	72.387	35.59	73.942	33.99
20	75.117	54.05	74.472	44.88	73.587	41.82	72.682	40.85	73.082	38.93	73.722	36.22	72.422	36.05	73.977	34.28
17	74.541	48.14	73.616	36.53	73.156	37.13	72.326	36.57	72.496	34.10	73.306	32.34	72.141	32.30	73.586	31.01
16	74.300	45.67	73.826	38.57	73.015	35.59	72.195	35.00	72.295	32.44	73.105	30.47	72.130	32.15	73.415	29.58
13	73.686	39.37	73.306	33.51	72.566	30.70	71.796	30.20	71.851	27.96	72.686	26.56	71.741	26.96	72.966	25.83
14	73.671	39.21	73.241	32.88	72.536	30.37	71.761	29.78	71.726	27.75	72.686	26.56	71.741	26.96	72.936	25.58
15	73.636	38.85	73.211	32.59	72.501	29.99	71.756	29.72	71.676	27.34	72.631	26.04	71.711	26.56	72.876	25.08
10	72.830	30.58	72.565	26.29	71.990	24.43	71.305	24.30	71.005	21.81	72.145	21.51	71.365	21.93	72.395	21.06
11	72.848	30.77	72.498	25.64	71.908	23.53	71.233	23.43	70.873	20.72	72.068	20.79	71.308	21.17	72.353	20.71
12	72.425	26.43	72.145	22.20	71.560	19.74	70.885	19.25	70.435	17.11	71.685	17.22	71.040	17.59	71.940	17.26
9	72.093	23.02	71.848	19.30	71.383	17.81	70.753	17.67	70.203	15.20	71.528	15.75	70.953	16.43	71.753	15.69
8	71.486	16.79	71.396	14.89	71.016	13.81	70.466	14.22	69.666	10·78	71.191	12.61	70.776	14.07	71.396	12.71
7	70.916	10.94	70.966	10.70	70.666	10.00	70.146	10.37	69.286	7·65	70.871	9.62	70.531	10.79	71.101	10.24
Mean).S. L.	69.850	..	69.868	..	69.748	..	69.283	..	68.358	..	69.840	..	69.723	..	69.875	..

Pipe No. 31 is the standard pipe f

TABLE II.

UPSTREAM OF THE MODEL ON THE PERCENTAGE EFFECTIVE PRESSURE.

Depth of silt.—¾" %Effective Pressure.	Head 11.967 Actual Pressures.	Depth of silt.—1" %Effective Pressure.	Head 12.774 Actual Pressure.	Depth of silt.—1" %Effective Pressure.	Head 11.674 A ctual Pressure.	Depth of silt.—1 1/16" %Effective Pressure.	Head 11.644 Actual Pressure.	Depth of silt.—1⅛" %Effective Pressure.	Head 7.332 Actual Pressure.	Depth of silt.—1⅛" %Effective Pressure.	Head 10.776 Actual Pressure.	Depth of silt.—1¼" %Effective Pressure.	Head 11.164 Actual Pressure.	Depth of silt.—1¼" %Effective Pressure.	Head 11.124 Actual Pressure.	Depth of silt.—1⅜" %Effective Pressure.
..	81.842	..	81.087	..	79.982	..	81.547	..	77.242	..	80.679	..	81.037	..	81.037	..
60.34	76.840	58.20	76.005	60.22	75.210	59.12	76.520	56.84	74.030	56.19	75.910	55.74	75.800	53.09	75.650	51.59
56.05	76.424	54.73	75.489	56.18	74.759	55.26	76.059	52.88	73.719	51.95	75.469	51.65	75.389	49.41	75.279	48.26
49.80	75.656	48.31	74.611	49.30	73.921	48.08	75.361	46.89	73.281	45.98	74.881	46.20	74.776	43.92	74.626	42.39
49.85	75.630	48.09	74.610	49.30	73.910	47.99	75.315	46.49	73.280	45.96	74.830	45.72	74.710	43.33	74.610	42.25
47.34	75.307	45.39	74.217	46.22	73.592	45.26	75.057	44.28	73.107	43.60	74.597	43.56	74.642	42.72	74.382	40.20
46.90	**75.289**	**45.24**	**74.134**	**45.57**	**73.524**	**44.68**	**75.014**	**43.91**	**73.094**	**43.43**	**74.549**	**43.11**	**74.434**	**40.85**	**74.314**	**39.59**
44.67	75.087	43.55	73.952	45.14	73.372	43.38	74.817	42.22	72.987	41.97	74.372	41.47	74.287	39.54	74.222	38.76
44.38	74.985	42.70	73.860	43.42	73.260	42.42	74.750	41.64	72.920	41.05	74.300	40.80	74.180	38.58	74.140	38.03
44.26	74.996	42.79	73.891	43.67	73.271	42.51	74.746	41.61	72.931	41.20	74.311	40.91	74.201	38.77	74.146	38.08
43.45	74.936	42.29	73.746	42.53	73.116	41.19	74.691	41.14	72.906	40.86	74.281	40.63	74.211	38.86	74.116	37.81
42.65	74.746	40.70	73.621	41.55	73.011	40.29	74.536	39.80	72.771	39.02	74.071	38.68	74.011	37.07	73.921	36.06
42.39	74.776	40.95	73.586	41.28	73.011	40.29	74.556	39.98	72.806	39.50	74.101	38.96	74.016	37.11	73.971	36.51
39.51	74.436	38.11	73.221	38.42	72.676	37.42	74.226	37.14	72.646	37.32	73.836	36.50	73.716	34.42	73.706	34.13
38.87	74.348	37.38	73.078	37.30	72.547	36.31	74.138	36.39	72.538	35.84	73.768	35.87	73.618	33.55	73.608	33.25
37.40	74.133	35.58	72.823	35.38	72.358	34.69	73.963	34.88	72.413	34.14	73.563	33.96	73.473	32.25	73.438	31.72
36.23	74.000	34.47	72.645	33.91	72.150	32.91	73.820	33.66	72.360	33.42	73.465	33.06	73.375	31.37	73.310	30.57
35.15	73.884	33.50	72.554	33.20	72.089	32.39	73.714	32.75	72.264	32.11	73.344	31.93	73.244	30.20	73.234	29.89
35.59	73.942	33.99	72.627	33.77	72.127	32.71	73.767	33.20	72.292	32.49	73.412	32.56	73.292	30.63	73.267	30.18
36.05	73.977	34.28	72.682	34.20	72.207	33.40	73.817	33.63	72.332	33.03	73.442	32.84	73.342	31.07	73.282	30.32
32.30	73.586	31.01	72.131	29.89	71.691	28.98	73.401	30.06	72.086	29.68	73.096	29.63	73.006	28.06	72.996	27.75
32.15	73.415	29.58	71.935	28.35	71.530	27.60	73.245	28.74	71.985	28.30	72.920	28.00	72.855	26.71	72.825	26.21
26.96	72.966	25.83	71.334	23.65	71.056	23.54	72.811	24.99	71.711	24.56	72.536	24.43	72.441	23.00	72.466	22.98
26.96	72.936	25.58	71.331	23.63	71.021	23.24	72.806	24.95	71.706	24.50	72.521	24.29	72.431	22.91	72.456	22.90
26.56	72.876	25.08	71.331	23.63	70.971	22.81	72.726	24.26	71.681	24.15	72.466	23.78	72.401	22.64	72.401	22.40
21.93	72.595	21.06	70.710	18.76	70.440	18.26	72.300	20.61	71.390	20.19	72.055	19.97	71.995	19.01	72.010	18.89
21.17	72.353	20.71	70.548	17.50	70.263	16.75	72.228	19.99	71.338	19.48	71.998	19.44	71.943	18.54	71.958	18.42
17.59	71.940	17.26	70.215	14.89	69.980	14.32	71.870	16.91	71.070	15.82	71.645	16.17	71.590	15.38	71.595	15.16
16.43	71.753	15.69	69.893	12.37	69.693	11.86	71.693	15.39	71.023	15.18	71.543	15.22	71.453	14.15	71.488	14.20
14.07	71.396	12.71	69.291	7.66	69.221	7.82	71.366	12.59	70.841	12.70	71.206	12.09	71.166	11.58	71.186	11.48
10.79	71.101	10.24	68.776	3.62	68.721	3.54	71.096	10.27	70.651	10.11	70.956	9.77	70.926	9.43	70.936	9.24
..	69.875	..	68.313	..	68.308	..	69.900	..	69.910	..	69.903	..	69.873	..	69.908	..

Pipe No. 31 is the standard pipe for reference.

TABLE III.

THE COMPARISON OF PERCENTAGE EFFECTIVE PRESSURE UNDER THE MODEL AND THE PRO

Pipe No.	Model.	Prototype.	Difference.	Model.	Prototype.	Difference.	Model.	Prototype.	Difference.	Model.	Prototype.	Difference.	Model.	Proto
35	51.65	50.78	.87	64.55	62.91	1.64				59.37	58.50	.87	73.21	72.
36	46.20	43.87	2.33	57.42	57.42	.00	45.98	48.48	2.50	49.89	49.43	.46		
33	45.72	42.30	3.42	56.93	56.87	.06	45.96	45.27	.69	49.79	49.43	.34	66.06	65.
32	43.56	42.67	.89	53.71	55.22	1.51	43.60	46.65	3.05	46.79	48.07	2.28		
31	**43.11**	**41.94**	**1.17**	**53.61**	**53.30**	**.31**	**43.43**	**44.36**	**.93**	**46.44**	**45.80**	**.64**	**60.44**	**59**
30	41.47	41.75	.28				42.08	44.66	2.58					
29	40.80	41.66	.86	50.56	52.75	2.19	40.94	45.27	4.33	43.71	46.26	2.55	58.36	59.
28	40.91	40.83	.08	50.75	51.37	.62	41.20	44.66	3.46	43.94	45.35	1.41		
24	38.68	39.91	1.23	48.59	52.75	4.16	39.02	42.84	3.82	41.75	42.40	.65		
16	36.50	37.51	1.01				37.32	39.94	2.62	38.78	42.86	4.08		
23	35.87	36.96	1.09	44.53	46.43	1.90	35.84	39.63	3.79	37.70	40.59	2.89	49.70	52.
22	33.97	35.02	1.06	42.12	43.68	1.56	34.14	37.35	3.21	35.78	38.55	.23		
21	23.06	34.47	1.41	41.12	42.58	1.46	33.42	36.43	3.01	34.38	37.64	3.26	43.74	46.
18	31.93	32.90	.97	40.03	40.93	.90				33.74	34.47	.73	44.36	43.
17	29.63	31.89	2.26	36.57	39.01	2.44	29.68	32.93	3.25	30.37	34.47	4.10		
16	28.00	30.78	2.78	35.00	37.09	2.09	28.20	32.01	3.71				38.37	38.
13	24.43	25.81	1.38	30.20	31.87	1.67	24.56	27.90	3.34	25.25	29.48	4.23		
14	24.29	26.64	2.35	29.78	32.69	2.91	24.50	27.90	3.40	25.07	29.48	4.41		
10	19.97	20.18	.21	24.30	25.00	.70	20.19	21.65	1.46	19.49	22.68	3.19	26.29	26.
9	15.22	17.60	2.38	17.67	20.62	2.95	15.18	18.75	3.57	14.40	18.58	4.18	19.30	20.
8	12.09	10.32	1.77	14.22	11.81	2.41	12.70	10.21	2.49	9.58	8.62	.96		
7	9.77	6.64	3.13	10.37	7.69	2.68	10.11	7.01	3.10	7.84	5.22	2.62	10.70	6.6

Pipe No. 31 is the Standard Pipe for referen

TABLE III.

ERCENTAGE EFFECTIVE PRESSURE UNDER THE MODEL AND THE PROTOTYPE FOR SIMILAR SILT CONDITIONS UPSTREAM.

otype.	Difference.	Model.	Prototype.	Difference.	Model.	Prototype.	Difference.	Model.	Prototype.	Difference.	Model.	Prototype.	Difference.	Model.	Prototype.	Difference.
		59.37	58.50	.87	73.21	72.00	1.21	52.88	54.52	1.64	55.26	53.80	1.46	56.18	55.45	.73
8.48	2.50	49.89	49.43	.46				46.89	46.45	.44				49.30	47.74	1.56
5.27	.69	49.79	49.43	.34	66.06	65.10	0.96	46.49	47.42	.93	47.99	46.59	1.40	49.30	48.50	.80
6.65	3.05	46.79	48.07	2.28				44.28	46.77	2.49	45.26	46.20	.94	46.22	46.43	.21
4.36	**.93**	**46.44**	**45.80**	**.64**	**60.44**	**59.50**	**0.94**	**43.91**	**43.87**	**.04**	**44.68**	**44.05**	**.63**	**45.57**	**45.49**	**.08**
4.66	2.58							42.22	43.87	1.65	43.38	44.44	1.06			
5.27	4.33	43.71	46.26	2.55	58.36	59.20	0.84	41.64	43.87	2.23	42.42	44.44	2.02	43.42	44.74	1.32
4.66	3.46	43.94	45.35	1.41				41.61	42.58	.97	42.51	45.61	3.10	43.67	43.98	.31
2.84	3.82	41.75	42.40	.65				39.80	40.00	.20				41.55	42.11	.56
9.94	2.62	38.78	42.86	4.08				37.14	35.81	1.33	37.42	36.84	.58	38.42	39.85	1.43
9.63	3.79	37.70	40.59	2.89	49.70	52.00	2.30				36.31	38.40	2.09	37.30	39.91	1.61
7.35	3.21	35.78	38.55	.23				34.88	34.19	.69	34.69	38.40	3.71	35.38	36.84	1.46
6.43	3.01	34.38	37.64	3.26	43.74	46.10	2.36	33.66	32.58	1.08	32.91	35.87	2.96	33.91	34.96	1.05
		33.74	34.47	.73	44.36	43.80	0.56	32.75	30.65	2.10	32.39	32.55	.16	33.20	34.21	1.01
2.93	3.25	30.37	34.47	4.10				30.06	28.06	2.00	28.98	30.21	1.23	29.89	33.08	3.19
2.01	3.71				38.57	38.80	0.23	28.72	28.39	.33	27.60	29.43	1.83	28.35	31.77	3.42
7.90	3.34	25.25	29.48	4.23				24.99	22.90	2.09	23.54	29.04	5.50	23.65	28.20	4.55
7.90	3.40	25.07	29.48	4.41				24.95	23.55	1.40	23.24	29.82	6.58	23.63	28.38	4.75
1.65	1.46	19.49	22.68	3.19	26.29	26.50	0.21				18.26	21.83	3.57	18.76	22.93	4.17
8.75	3.57	14.40	18.58	4.18	19.30	20.50	1.20									
0.21	2.49	9.58	8.62	.96												
7.01	3.10	7.84	5.22	2.62	10.70	6.60	4.10									

Pipe No. 31 is the Standard Pipe for reference.

TABLE IV.

SHOWING THE EFFECT OF WITHDRAWAL OF SILT UPSTREAM OF THE MODEL ON PERCENTAGE EFFECTIVE PRESSURE.

Pipe No.	Head 10.557 Actual Pressure.	Depth of silt. ¾" %Effective Pressure.	Head 10.559 Actual Pressure.	Depth of silt. ½" %Effective Perssure.	Head 10.142 Actual Pressure.	Depth of silt. ¾" %Effective Pressure.	Head 8.964 Actual Pressure.	Depth of silt. Nil. %Effective Pressure.
Mean U.S.L.	80.452		80.454		80.037		78.804	
34	76.795	65.36	77.285	69.99	77.330	73.31	78.250	93.82
35	76.364	61.28	77.009	67.37	77.094	70.98	77.659	87.23
36	75.811	56.04	76.486	62.42	76.551	65.63	76.656	76.04
33	75.740	55.37	76.385	61.46	76.475	64.88	76.620	75.64
32	75.357	51.74	76.002	57.84	76.077	60.95	76.272	71.75
31	**75.259**	**50.81**	**75.899**	**56.86**	**75.959**	**59.79**	**76.164**	**70.55**
30	75.232	50.55	75.872	56.61	75.947	59.67	75.987	68.57
29	75.060	48.92	75.675	54.74	75.755	57.78	75.905	67.66
28	75.066	48.98	75.671	54.70	75.736	57.59	75.901	67.61
27	74.721	45.71	75.486	52.95	75.146	51.77	75.821	66.72
24	74.881	47.23	75.486	52.95	75.506	55.32	75.526	63.43
25	74.841	46.85	75.381	51.96	75.436	54.63	75.626	64.55
26	74.446	43.11	74.986	48.21	75.071	51.04	75.221	60.03
23	74.348	42.18	74.848	46.91	74.908	49.43	75.088	58.55
22	74.078	39.62	74.558	44.16	74.648	46.86	74.798	55.31
21	73.735	36.37	74.330	42.00	74.215	42.60	74.690	54.11
18	73.849	37.45	74.324	41.95	74.374	44.16	74.534	52.37
19	73.822	37.20	74.272	41.45	74.327	43.70	74.597	53.07
20	73.902	37.96	74.367	42.35	74.447	44.88	74.662	53.79
17	73.216	31.46	73.606	35.15	73.556	36.10	74.156	48.15
16	73.335	32.59	73.750	36.51	73.790	38.40	73.975	46.13
13	72.876	28.24	73.236	31.64	73.286	33.44	73.386	39.56
14	72.836	27.86	73.176	31.07	73.231	32.89	73.381	39.50
15	72.801	27.53	73.131	30.65	73.171	32.30	74.331	50.10
10	72.240	22.21	72.530	24.96	72.565	26.33	72.560	30.34
11	72.183	21.67	72.383	23.56	72.343	24.14	72.598	30.77
12	71.860	18.61	72.060	20.50	72.070	21.45	72.200	26.33
9	71.613	16.27	71.713	17.22	71.733	18.12	71.913	23.13
8	71.226	12.61	71.226	12.61	71.226	13.12	71.351	16.86
7	70.861	9.15	70.891	9.43	70.896	9.87	70.806	10.78
Mean D.S.L.	69.895		69.893		69.895		69.840	

Pipe No. 31 is the standard pipe for reference.

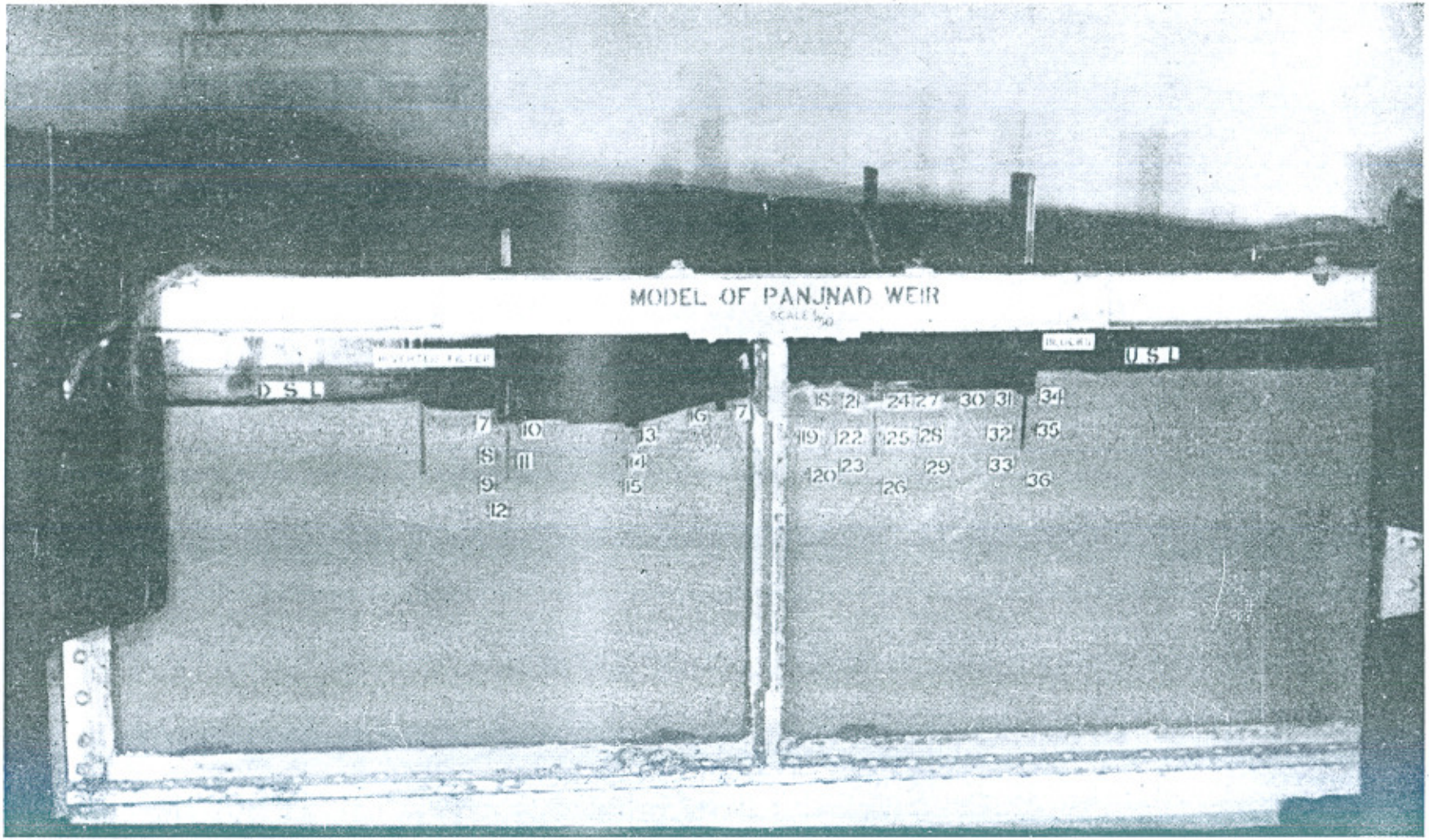
TABLE V.

SHOWING THE EFFECT OF REDUCTION OF TEMPERATURE ON THE PERCENTAGE EFFECTIVE PRESSURE.

	Time in minutes from the beginning of the experiment.								*Time in minutes after the process was reversed.*			
Pipe No.	0	20	40	60	140	170	210	240	30	45	70	120
34	58.20	53.09	51.59	51.56	47.77	47.15	45.89	45.10	45.58	46.50	47.30	47.57
35	54.73	49.41	48.26	48.10	36.02	44.24	42.72	41.90	42.32	43.01	44.13	44.40
36	48.31	43.92	42.39	42.37	39.10	39.03	37.56	36.89	37.16	37.89	38.87	39.05
33	48.09	43.33	42.25	42.13	38.88	38.62	37.29	36.84	36.97	37.70	38.33	38.78
32	45.39	42.72	40.20	40.27	37.01	36.84	35.33	34.75	34.97	35.92	36.46	36.91
31	**45.24**	**40.85**	**39.59**	**39.97**	**36.85**	**36.20**	**34.87**	**34.60**	**34.86**	**35.98**	**36.48**	**36.92**
30	43.55	39.54	38.76	38.51	35.34	34.86	33.58	33.62	33.78	34.82	35.28	35.63
29	42.70	38.58	38.03	37.55	34.84	34.63	33.30	32.99	33.24	34.01	34.47	34.82
28	42.79	38.77	38.08	37.61	34.85	34.64	33.35	32.86	33.29	34.06	34.52	34.79
27	42.29	38.86	37.81	37.38	34.68	34.11	32.69	32.21	32.72	33.53	33.95	34.48
24	40.70	37.07	36.06	35.59	33.10	32.62	31.03	31.25	31.40	32.21	32.54	33.03
25	40.95	37.11	36.51	35.99	33.36	33.01	31.55	31.64	31.76	32.48	32.67	33.07
26	38.11	34.42	34.13	33.57	31.26	30.82	29.49	29.54	29.91	30.37	30.65	31.01
23	37.38	33.55	33.25	32.60	30.31	29.91	28.72	28.73	29.14	29.59	29.79	30.50
22	35.58	32.25	31.72	31.21	28.95	28.68	26.74	27.59	27.86	28.45	28.82	29.48
21	34.47	31.37	30.57	30.41	28.31	27.82	26.94	26.82	27.14	27.85	28.10	28.36
18	33.50	30.20	29.89	29.42	27.52	26.84	26.09	26.07	26.21	26.83	27.16	28.35
19	33.99	30.63	30.18	29.94	27.94	27.27	25.56	26.31	26.80	27.12	27.45	27.81
20	34.28	31.07	30.32	30.21	28.16	27.71	26.82	26.70	26.98	27.69	27.85	28.24
17	31.01	28.06	27.75	27.42	25.30	24.80	24.09	23.94	24.25	24.47	25.03	25.29
16	29.58	26.71	26.21	25.84	24.15	23.60	22.94	22.79	23.10	23.32	23.75	23.96
13	25.83	23.00	22.98	22.30	21.00	20.54	20.01	19.87	20.21	20.39	20.68	20.85
14	25.58	22.91	22.90	22.16	20.96	20.49	19.79	19.78	19.24	20.34	20.50	20.72
15	25.08	22.64	22.40	22.21	20.70	20.27	19.66	19.52	19.77	19.95	20.33	20.50
10	21.06	19.01	18.89	17.98	17.14	16.66	16.19	16.14	16.42	16.59	16.89	17.15
11	20.71	18.54	18.42	17.60	16.68	16.25	15.69	15.78	15.97	16.14	16.43	16.69
12	17.26	15.38	15.16	14.61	13.85	13.59	13.16	13.12	13.30	13.43	13.73	13.98
9	15.09	14.15	14.20	13.47	12.87	12.56	12.40	12.19	12.36	11.78	12.61	12.86
8	12.71	11.58	11.48	11.03	10.53	10.22	10.14	10.16	10.15	10.23	10.35	10.47
7	10.24	9.43	9.24	8.83	8.47	8.33	8.17	8.15	8.22	8.21	8.29	8.41

Pipe No. 31 is the standard pipe for reference.

DIAGRAM 1.


MODEL OF PANJNAD WEIR
SCALE 1/40
D S L
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THE EFFECT OF ADDITION OF SILT
UP-STREAM OF THE MODEL ON THE
PERCENTAGE EFFECTIVE PRESSURE
UNDER THE FLOOR

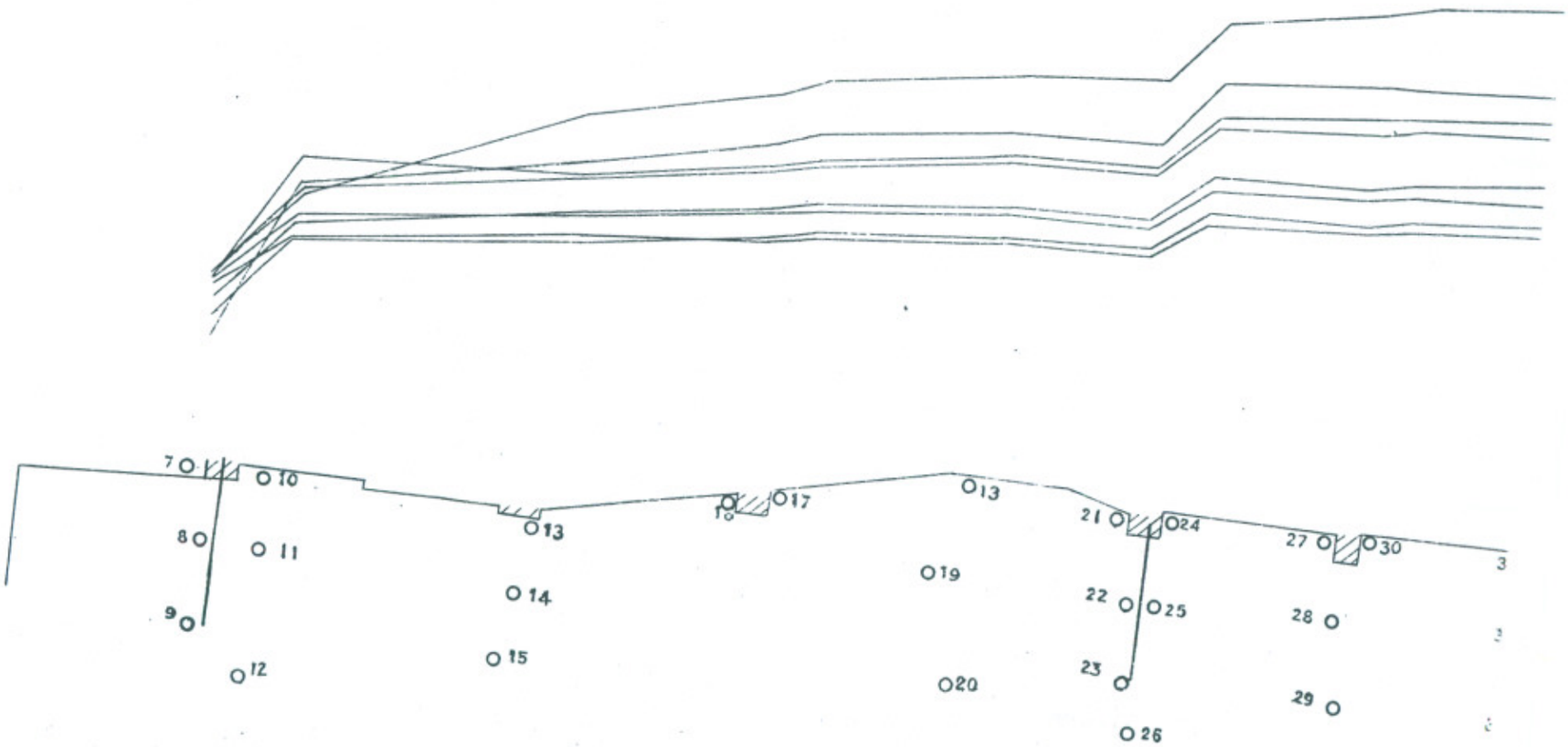
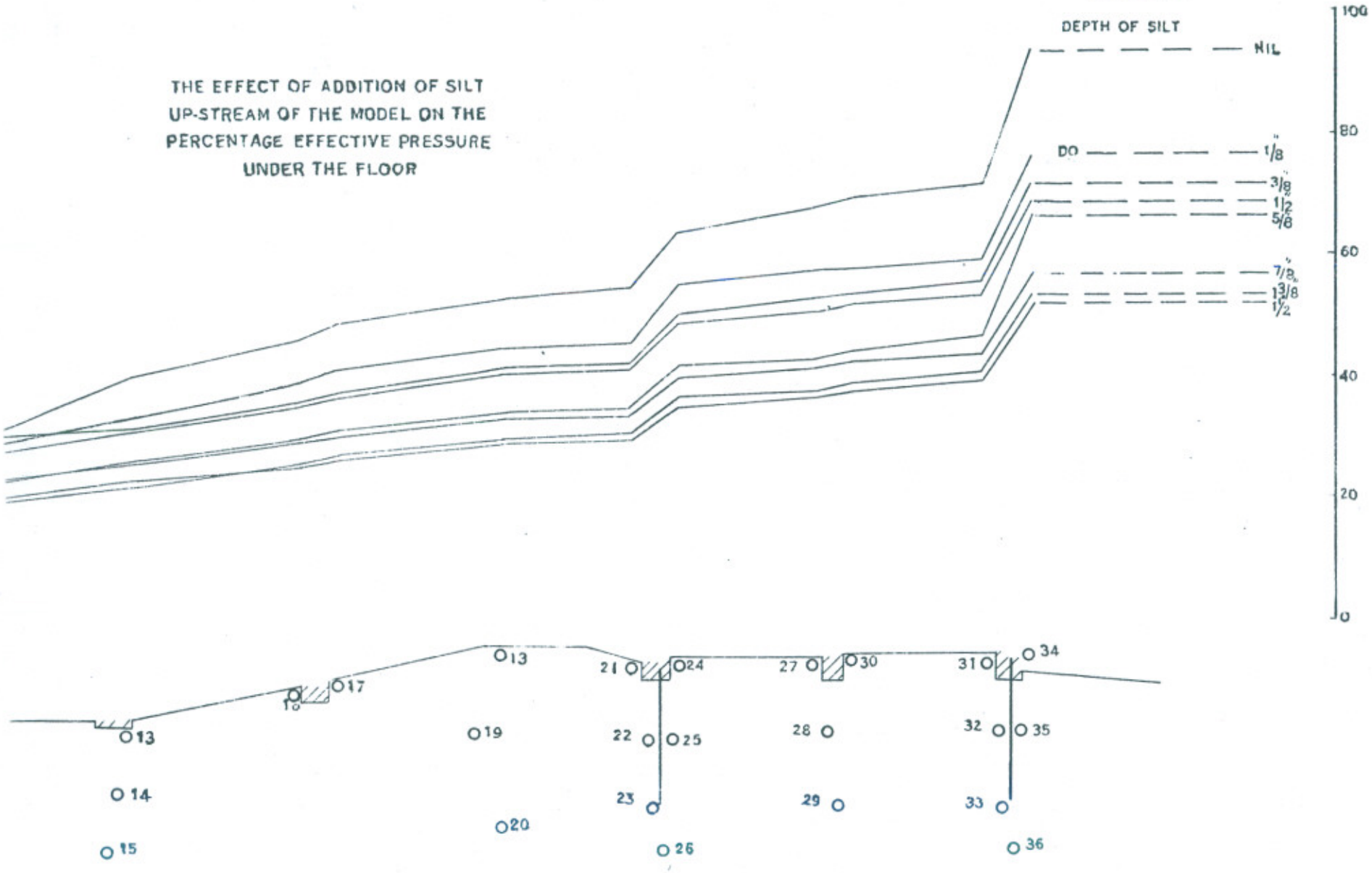


DIAGRAM II

THE EFFECT OF ADDITION OF SILT UP-STREAM OF THE MODEL ON THE PERCENTAGE EFFECTIVE PRESSURE UNDER THE FLOOR



REFERENCES

PROTOTYPE

MODEL

GRADIENT UNDER THE FLOOR IN THE MODEL AND IN THE PROTOTYPE FOR SIMILAR SILT CONDITIONS UP-STREAM.

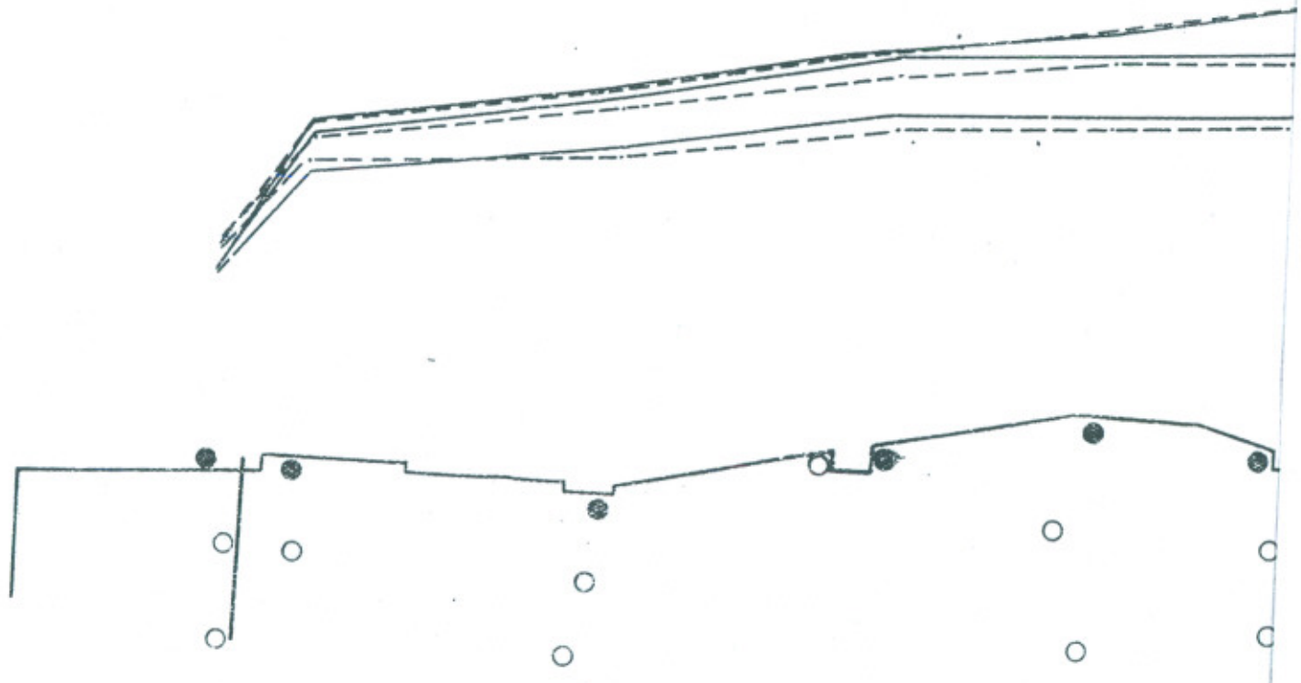
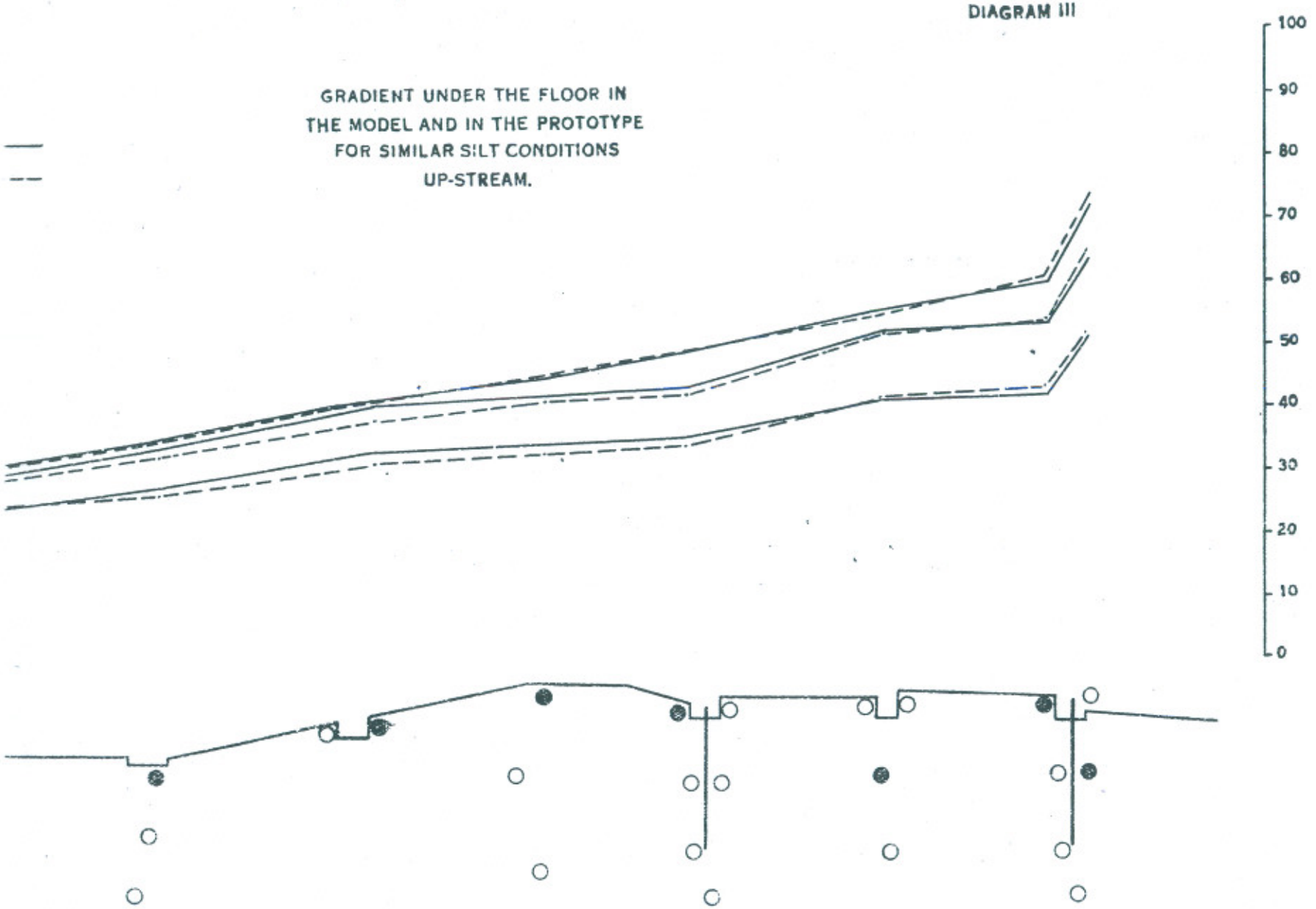


DIAGRAM III

GRADIENT UNDER THE FLOOR IN
THE MODEL AND IN THE PROTOTYPE
FOR SIMILAR SILT CONDITIONS
UP-STREAM.



THE EFFECT OF REDUCTION OF
TEMPERATURE ON THE PERCENTAGE
EFFECTIVE PRESSURE.

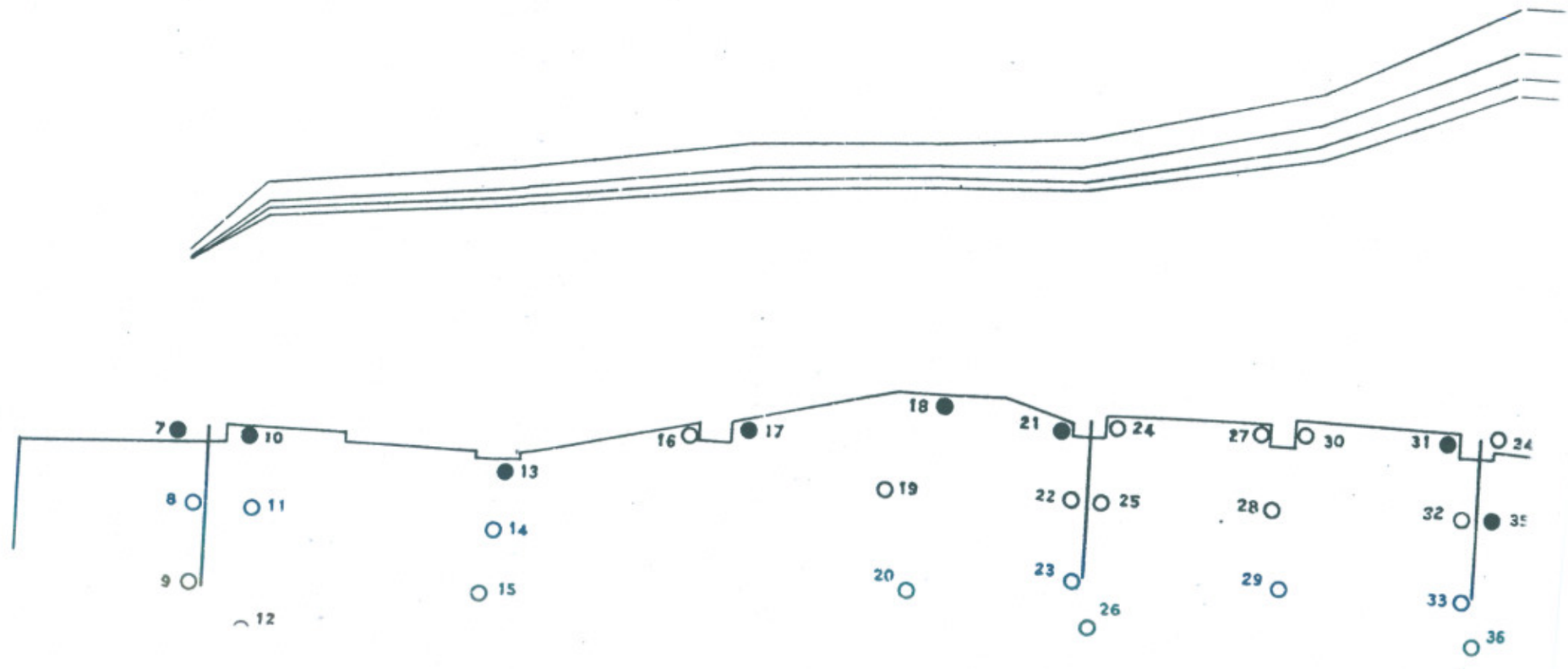


DIAGRAM IV.

THE EFFECT OF REDUCTION OF TEMPERATURE ON THE PERCENTAGE EFFECTIVE PRESSURE.

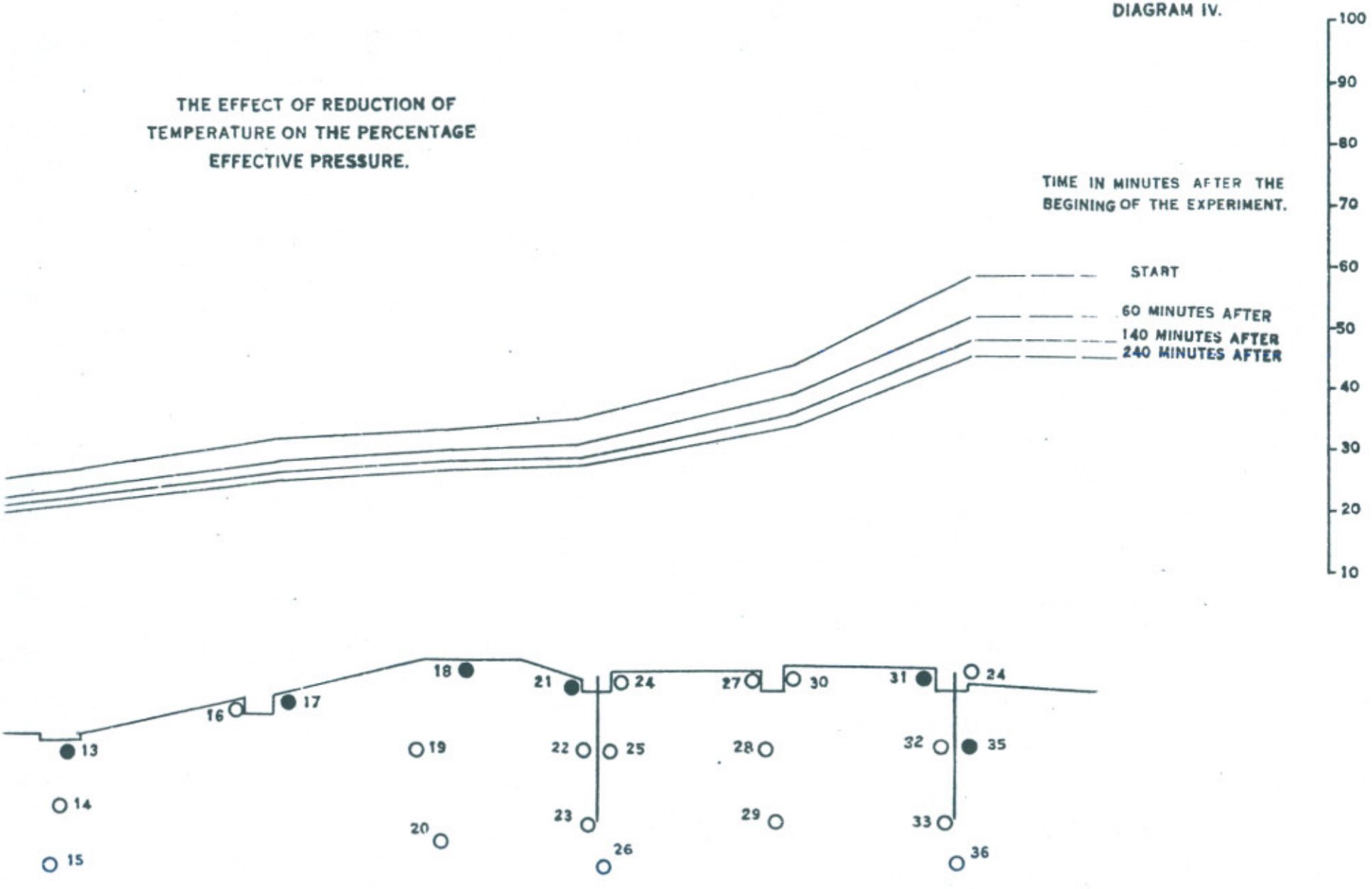


DIAGRAM V.

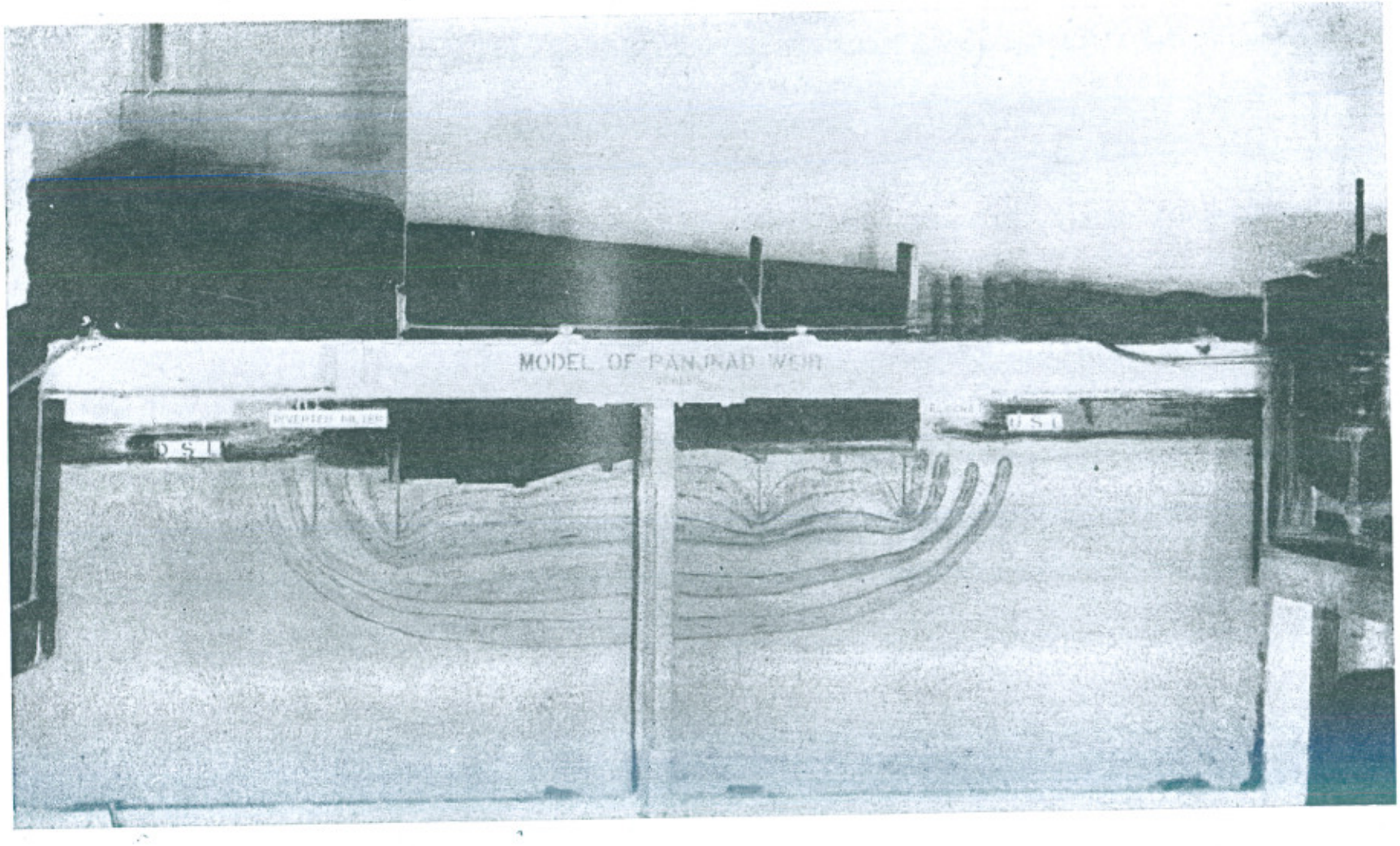
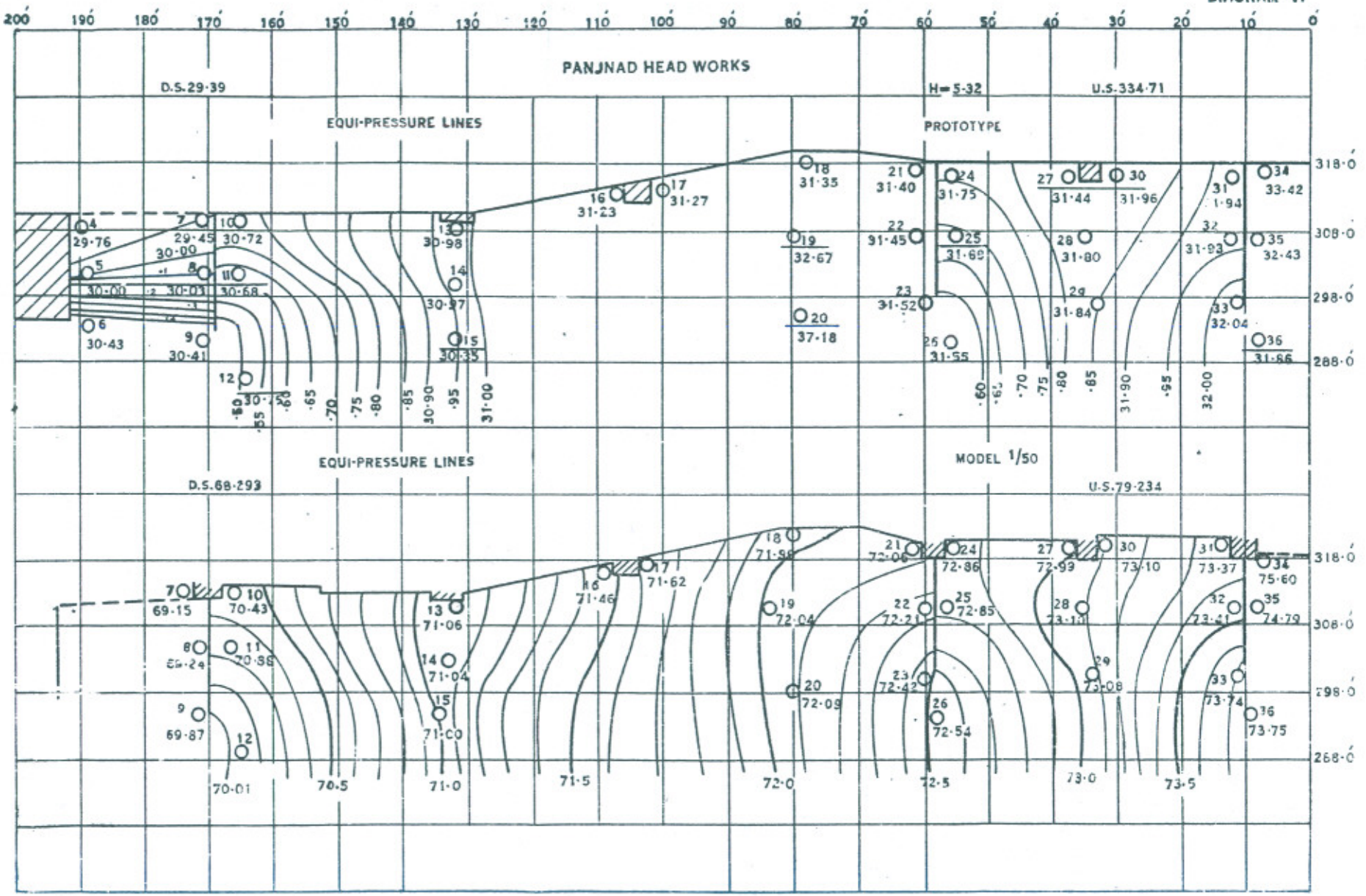


DIAGRAM VI


PANJNAD HEAD WORKS
D.S.29·39
U.S.334·71
H=5·32
EQUI-PRESSURE LINES
PROTOTYPE
MODEL 1/50
D.S.68·293
U.S.79·234
EQUI-PRESSURE LINES
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
318·0
308·0
298·0
288·0
268·0

DISCUSSION.

The **Author** in introducing his paper said that a number of investigations had been carried out in the Irrigation Research Institute on the flow of water under and on the pressures on simple and complicated forms of works. Before a general application of laboratory results to design could be made, it was essential to investigate a model of an existing work on which pressure pipe observations had been taken and determine the degree of agreement.

Panjnad Weir was the only work of its kind in the Punjab on which pressures had been recorded. A model of Panjnad Weir to a scale of 1/50 was constructed in a glass tank and the pressures were observed and the streamlines traced.

In Table I were shown the pressures under the weir with no silt deposit upstream and with uniform temperature under the work. Those pressures were the maximum pressures that will be experienced under Panjnad Weir. That was confirmed by a study of the Panjnad Weir observations over a period of three years.

Since the paper was submitted to the Congress a detailed investigation of the effect of temperature on the pressure under the work had been carried out. A number of thermometers were introduced into the sand at the same positions as the pressure observation pipes. Two thermometers were placed in the water at the upstream and downstream ends. One thermometer was placed outside close to the tank to record the temperature of the air. Diagram VII showed the exact location of thermometer points. Before actually starting the experiment the temperatures at all the thermometers were recorded. The temperature of the inflowing water was then raised by 5° C. and the experiment was allowed to continue for a number of hours. The temperature and pressure readings were taken simultaneously after regular intervals. The temperature of the inflowing water was then raised by 10° C. and the process repeated. This experiment was continued for 30 hours, and readings were taken after definite intervals of time. The effect of the fall in temperature of the inflowing water on the pressures was then studied. The temperature was lowered by 5° in one case, and 10° in the other. The temperature and pressure readings were taken in the same manner as described before. The data on the effect of temperature on the pressure obtained from those experiments is given in Tables VI—IX. The variation in the temperature of the upstream water was about 20° C. The temperature variations at those pipes at which thermometers were placed were also calculated, and the temperature gradients corresponding to the temperature of the inflowing water were plotted (Dia. VIII).

As the variation in temperature was fairly high at the pipes situated at the upstream end, the pressure drop at different temperatures were

plotted for those pipes (Dia. IX). The curves obtained were fairly regular and the effect of a unit rise or drop in temperature could be calculated.

The hydraulic gradients for various temperatures of the inflowing water were drawn (Dia. X). It would be seen that the pressures on the upstream portion of the work are high when the temperature of the inflowing water is high. When the temperature of the inflowing water is low, the pressures are also low.

It could be concluded from the above that the model, besides giving the true pressures under the work, successfully reproduced the effect of silt and temperature on pressures as experienced on the prototype.

A scour of 40 feet depth downstream of the pucca end occurred at the prototype during last summer.

It was reproduced on the model, and the effect on the pressures and the streamlines was studied.

Pressures obtained with and without the scour under similar conditions were given in Table X. This showed that the pipes situated near the downstream end a little away from the weir were mostly affected. Streamlines were also traced under the weir and are shown in Diagram XI. The courses of the streamlines except from point No. 1 are deflected towards the scour.

Dr. N. K. Bose said that before discussing the data presented in the paper, he would like to put before the members the analysis of the pressure observations presented by Mr. Khosla in the Congress Paper No. 162 and the subsequent observations taken at Panjnad. To be frank, that mass of data appeared to him hopelessly complicated and extremely difficult to analyse.

The speaker remarked that it was well-known that there was a silt-blanket on the upstream apron of every weir and the porosity and thickness of the blanket varied from month to month sometimes even from day to day. It was also well-known that the silt blanket could cut off a very considerable fraction of the total pressure which was generally taken as the difference between the upstream and downstream heads of water. It follows that the effective pressure that was dissipated as the seepage water flowed through the sand foundations of the weir was generally less than the total pressure as recorded by the difference of upstream and downstream heads. The speaker further said that the pressure observations at Panjnad were all worked as a percentage ratio between the pressure head recorded at a pipe measured from the downstream water level and the total pressure. They all show a faint suspicion of the working of a periodic factor whose effect was almost masked by the more powerful effect of the silt-blanket. To analyse that periodic factor it was therefore imperative to eliminate the effect of th

silt-blanket on the pressures recorded in the different pipes. The speaker said that it had been mentioned that silt-blanket cuts off pressure so that the effective pressure was different from the total pressure. Now Pipe No. 34 was just below the silt-blanket and as such would record the effective pressure. So that if we refer the pressure heads of different pipes to the corresponding pressures at Pipe No. 34, then the effect of the silt-blanket would be eliminated. Thus the pressure distribution in the sand medium was not affected by anything that was happening upstream of Pipe No. 34, provided all the pressures were worked as percentages of the pressures at Pipe No. 34. It would be equally true if any other pipe was taken as the pipe of reference.

The speaker further remarked that he had been able to eliminate the effect of the silt-blanket and in Diagram XII the members would see how the pressures fluctuated for different parts of the year. Those curves were clearly periodic suggesting that they were the effect of some periodic factor operating in the sand medium. Various explanations might be suggested for that ; what the speaker thought was the most probable was the following :—

Mr. Khosla had found that the temperature of the river water had a considerable range of variation and he it was who first suggested that the fluctuation in the temperature of the river water could produce the above mentioned fluctuations in the pressures. The speaker said that they had had a long discussion on that subject but failed to see how a uniform lowering or raising of temperature of water in the whole of the sand medium could affect the pressures. Suddenly they saw that it was not a uniform lowering but a differential lowering of the temperature that could do it. His physical conception of the process was something as described below.

Suppose they had a tube full of sand uniformly packed. If water at a uniform temperature be running through it and pressures were recorded at different points of the tube the pressure menisci would all lie on a slanting line. If now the inflowing water was cooled, the cold water, as it had greater viscosity while travelling in the sand medium would lose more head, so that by the time it reached the pressure Pipe I, more pressure would be lost than in any other part of the tube where the cold water had not as yet reached. These points are shown in Diagram XIII. As the cold water travelled on the pressures fall. So that if they take two Pressure Points II and III and take the ratio between Pressure Point III and Pressure Point II, that ratio would remain steady till the cold front reached II and then it would start falling till the maximum effect was recorded when it would begin rising.

The speaker further said that an experiment to verify that had been conducted in the Research Institute and Dr. V. I. Vaidhianathan would give the members all the details. That experiment would confirm the above supposition amply as the Table XII would show.

In Diagram XII the speaker had plotted the pressures at pipes 35, 36, 31, 29, 21 and 9 with reference to the pressure at Pipe No. 34. Each plotted point represented the average of about 30 to 40 observations taken in each month for the three years 1932, 1933 and 1934. Though those observations showed considerable scatter, statistically they could be averaged with an error band of $\pm 5\%$. These curves showed another peculiarity. The maximum points for those curves were different, for Pipe 35, the pipe nearest the upstream, it occurred in the month of August whereas for Pipe 9, the pipe nearest the downstream, it occurred in October—a time interval of $1\frac{1}{2}$ months, just about the time that water took to travel from Pipe 35 to Pipe 9. That added additional confirmation to the suggestion that the effect was due to some factor that was carried along by the flowing water.

The speaker said that the author had been able to reproduce those effects more or less completely. The effect of the silt blanket had been obtained by him almost fully, whereas the effect of temperatuse only partially.

Pipe No. 36 was in the direct flow, whereas Pipe 31 was in a very slow flow, still they showed the same percentage drop for the same temperature difference. It might be enquired if the effect of temperature could raise the pressures so high as to render the weir unsafe. In Diagram I it would be seen that the model pressures with no silt under uniform temperature were shown by broad straight lines. Those lines were generally higher than the average value of the pressure as determined from the periodic curves.

Dr. V. I. Vaidhianathan described the experiments on the effect of temperature on the sub-soil pressures carried out in the Institute at Lahore. In the tests carried out a small tube was filled with sand and pressure pipes were inserted into this tube at various intervals. He then showed the diagram of the arrangement. When water in the tube was at a uniform temperature, the fall of pressure from the upstream end was uniform having the same gradient throughout. When cold water was allowed to enter at one end the gradient changed and the line joining the menisci in the side manometers became convex to the axis of the tube in which the sand was packed. If warm water was allowed to enter the tube, this line became concave. The temperature difference between the upstream and the downstream end was about 9° C. in one of the experiments and the change observed in one of the pressure tubes was about 8 per cent. He said that this lent support to the idea of induced stratification and partly explained the abnormalities observed by Mr. Khosla on the pressure pipe observations in the Panjnad Weir.

He then explained how the temperature difference introduced a continuous change in the viscosity of the water flowing in the sand medium and how this caused the change of pressure observed in the experiment and in the models.

Mr. Khosla said that he was afraid that his criticism was going to be longer than the paper itself. The matter printed in it had been the subject of intensive study with him for the last six years. The paper was, in effect, a continuation of his own Paper No. 162 on the Panjnad observations and of the recent publication No. 8 of the Central Board of Irrigation.

The speaker further said that it had been his good fortune—thanks to the courtesy of Dr. McKenzie Taylor and Mr. Harbans Lal Uppal—to be associated with that experimental work in all stages of its development. It was a matter of sincere joy to him that his work in the field had been tested in full, and that his conclusions had now received the seal of confirmation from laboratory tests. The confirmation of his conclusion that all the seasonal variations in uplift pressures could be fully explained by variations in temperature and depth of silt deposits on the upstream and downstream pervious floors, was one of the most outstanding contributions of the province.

The speaker further remarked that the paper was one of fundamental importance. It afforded definite confirmation of some of the most important and fundamental conclusions in the science of subsoil hydraulics. In the entire history of research on the subject that was the first paper which had definitely established the fact that the field results could be almost completely reproduced on models.

There had been in the past suggestions that it could be done but nowhere before had it actually been done. The use of models in that branch of research was not original to the Punjab, but the high technique developed there with regard to model work and the results obtained thereby, excelled anything of a similar nature that had been done anywhere else in the world. That brilliant achievement was due to the able direction and personal work of Dr. McKenzie Taylor and the loyal co-operation of his officers. The profession owed a deep debt of gratitude to Dr. McKenzie Taylor who in the short space of two to three years had made such a remarkable advance in that branch of research by means of models.

The speaker said that the gratitude of the profession was no less due to Mr. Harbans Lal Uppal, who by his untiring application and consummate experimental skill, had produced results of such fundamental importance.

The contributions of Dr. N. K. Bose and Dr. Vaidhianathan also deserved to be acknowledged.

The speaker further said that the very brief paper represented work of over three months, during most of which time the author was at his model day and night. That was why in such a short space he had succeeded in producing results which most other workers would take almost a whole year to do with much less success.

It was gratifying to note that the Punjab which gave the first lead on the subject, continued to lead in every subsequent advance. The failure of Bay No. 1 of the Khanki Weir in 1895 led to Colonel Clibbon's historic experiments of 1896 with Khanki sand at Roorkee.

Subsequently came Bligh's theory of creep which though not quite faithful to the experimental results it sought to embody—was none the less a step forward. The experimental work at the Jaurian and Dugri Siphons of the Upper Chenab Canal (1928-29-30, Papers 138 and 142) showed that the creep theory was inadequate and even dangerous and pointed to the necessity for further research to enable designs to be based on more rational lines. A series of pressure pipes were very carefully fixed in the Panjnad Weir at suitable points below the floor (1930-31) and careful and regular observations were made from May 1932 onwards. The results of those observations were presented as Paper No. 162 at the 1933 Session of the Punjab Engineering Congress. Some conclusions were arrived at which were meant to be further tested before final acceptance. The need for further research work both in field and laboratory was clearly indicated.

Mr. Hadow in his criticism suggested that the conclusions of Panjnad might be tested on a scale model.

The main conclusions of Paper No. 162 were :—

1. $\frac{P}{H}$ or ϕ was independent of (*a*) head, (*b*) upstream and downstream levels, (*c*) of the porosity of the subsoil so long as the latter was free from stratification. (See Publication 8 of Central Board of Irrigation.)

But it was dependent on :

(*a'*) the depth of silt deposits on the upstream and downstream pervious floors.

(*b'*) temperatures of inflowing water and subsoil.

2. The outer vertical contacts were, length for length, more effective in reducing uplift pressures than the horizontal contacts ; that inner vertical contacts were no more effective than the horizontal ones.

3. The upstream and sheet pile line was more effective than the downstream end one.

4. There was always a residual head at the exit end, which, if in excess of the safe values, would cause progressive erosion of the subsoil which would gradually work back and might in an extreme case result in the failure of the work. That paper afforded confirmation of all the above conclusions. The author had, however, only dealt with (*c*) and 1 (*a'*) *i.e.*, that ϕ was independent of porosity but dependent on silt.

Conclusions 1 (*a*) and (*b*) : ϕ is independent of head and upstream and downstream levels. The author had enough results from that model as well as from others which amply proved that. It would be desirable to bring all that specifically on record.

Conclusion 1 (*c*) : ϕ is independent of pore space and particle diameter.

The model was on a scale of 1/50 but particle diameter or the pore space were not reproduced on any scale. Since the results in the model and the prototype agreed in spite of that, it was evident that ϕ was independent of porosity.

Conclusion 2 : A reference was invited to Diagram XIV. It had been prepared in a rather novel but very effective manner. The pressures at different pipes under normal conditions of flow, *viz.*, no silt upstream or downstream and temperature of inflowing and subsoil waters being the same, were projected on to diagonal line (2) from the vertical axis representing ϕ. The intersections of those projections with line 2 were projected again on the horizontal base. Those vertical projection lines were taken to represent the position of the various pipes.

Observations for conditions other than normal were plotted on these verticals for the various pipes.

It would be noticed that all those plots lay on straight lines which converge to a common origin. The numbers of the various lines correspond to the numbers of columns in Statement No. XI from which those lines had been plotted.

On the base the outer and inner vertical faces had been prominently shown by thick lines. The relative effectiveness of each vertical and horizontal contact was shown at the bottom. Assuming the upstream face contact of upstream pile line to be of unit effectiveness, the effectiveness of the inner vertical contacts ranged between 0.21 to 0.38, of the horizontal between 0.14 to 0.20. That fully proved conclusion No. 2.

Conclusion 3 : The outer vertical contact of the downstream pile line was only 0.63 against 1.0 effectiveness of the outer contact of the upstream pile line. That proved conclusion No. 3.

4. Lastly the residual head was as much in evidence in the model as in the prototype. Mr. Uppal would do well to take some observations of pressure just 6″ below the downstream floor and would see whether the point shown as (×) in the diagram represented the downstream floor level.

That residual head was the measure of the emergent gradient. The safety of works would depend on that gradient being kept within safe limits.

Scale model and Electric Analogy. At first the author read in his results only one thing that the results of prototype were reproducible on models by the addition of a suitable class and depth of silt and was apparently quite content with that. But the speaker pointed out to him that there was far more in the paper than he had suspected and that the results under normal flow conditions in the scale model agreed almost exactly with those obtained by Hebert (U.S.A.) with his electrical analogy model of Panjnad Weir.

The securing of that agreement was one of the most remarkable achievements of that experimental work and a most important contribution to the science of subsoil hydraulics. Till now the possibility of such agreement, though not ruled out, was considered remote. Attempts were made by Lane and Hebert of the U. S. A. Bureau of Reclamation to get such agreement but without success. They failed to take into account the effect of silt and temperature.

The success in the present case was due to the fact that silt and temperature had been considered. Three major precautions taken in conducting the model experiments were as below and were also responsible for the success.

(1) The elimination of all foreign matter from inflowing water by passing it through glass wool filters. That improvement in technique appeared too, had been the direct outcome of Dr. Bose's criticism and his insistence on a high degree of agreement betwen the observed and calculated values if model results were to be acceptable.

(2) The pile lines being made absolutely watertight.

(3) The readings being of a very high degree of accuracy.

The failure of previous experimenters to achieve results had been due to partial or total lack of the above precautions.

Temperature Effect. At Panjnad it was noticed that, silt deposits upstream and downstream remaining unaltered, the uplift pressures increased with increase of temperature and *vice versa*. An explanation for this phenomenon was sought in the viscosity changing with temperature and thus setting up what had been called " induced stratification " in the Central Board of Irrigation—Publication No. 8.

To test the correctness of that hypothesis Dr. Vaidhianathan carried out the first set of experiments with a soil tube (see Publication No. 8). Those tests established that the pressures went up with the temperature if the inflowing water was higher than that of the subsoil and *vice versa*. The departure from the normal gradient line was, however, comparatively small. A temperature difference of $\frac{8^\circ}{\phi}$ F. gave a rise or fall of pressures of $\frac{6}{\%}$ only. The absolute temperature of the water did not appear to have much effect. The change appeared to be due only to the temperature difference between the inflowing water and the subsoil.

Those tests were next carried out by Mr. Harbans Lal Uppal on the model of the Panjnad Weir which was in operation at the time. Those confirmed the qualitative conclusions of Dr. Vaidhianathan but the departure from the normal gradient line was much greater, *viz.*, 23 per cent. for a temperature difference of 17.7° F. This high variation was apparently due to the surface silt deposits leaving a much smaller transmission constant than the subsoil.

Any definite conclusion from that would be premature but it appeared that variations in pressures due to temperature were much greater in stratified soils than in homogeneous ones. Further tests were being carried out by Mr. Harbans Lal Uppal, and it was hoped that he would be in a position to add to existing knowledge.

On page 131, the Author suggested that "the results were inconclusive so far as Khosla's suggestion was concerned." While the results of subsequent experiments—then in progress—may point to certain modifications, the results freshly obtained after writing the paper were conclusive proofs that the temperature effect was definite and determinate. The Author had applied the test of reversibility in case of silt deposits. Applying the same tests to the temperature result given in Table V, it would be seen that with the process reversed, the results were almost exactly reproduced. Compare the results 140 minutes after start and 120 minutes after reversal. For facility of reference those were reproduced in Statement XI, as columns 18 and 19. Again comparing results 40 minutes after start (Table V) with last column of Table II and with 1 " silt (see columns 17 and 15 of Statement No. XI) the results were absolutely identical.

Thus the effect of temperature and silt was partly interchangeable, though it must be realized that while silt (see Diagram No. XIV) in the limit could almost entirely eliminate uplift pressures below the floor, the range of temperature being limited, its effect would also be limited. It further appeared that the more tight the silt the greater would be the effect of temperature. In a sandy subsoil with no silt deposits the temperature effect, though definite, will be small.

Again the effect of silt would be absolutely proportional all along the floor but in the case of temperature it would be differential and there would be small departures from proportionality due to local temperature gradients. Silt could only reduce pressures, whereas temperature could both reduce and raise pressures. These were the two essential points of difference in the case of silt and temperature.

In that connection it would be interesting to repeat the test with the addition of silt of the same class as the body of the subsoil. It is believed that the range of variation (line 1 to line 8) obtained with fine silt would not be possible in that case even with much deeper deposits.

Statement No. XI contained a selection of results which were best calculated to bring out the salient points of the paper. Columns 2 and 3 gave the results of the scale model and of the electric analogy model.

Columns 4 to 17 showed the results obtained from the model and the prototype. The agreement in all cases was remarkably close.

Columns 17 to 19 showed the results of temperature tests.

The details of head, silt and temperature of river and subsoil waters were given in the head lines.

Column 20 showed the minimum recorded values of ϕ or percentage pressures. Compare lines 2 and 20 on the diagram. They were plotted from columns 2 and 20 of the statement. That showed on the prototype the pressures could drop as low as 39·2 % of the normal due to temperature, silt or both. The maximum recorded values of ϕ were given in column 5 which was represented by curve 4. Thus the seasonal variations in the prototype ranged between lines 4 and 20.

In column 21 were given the highest pressures so far recorded at Panjnad. They were only about 70% of the theoretical pressures (see column 27). Thus nature always had given a certain factor of safety and the fact should be kept in mind at the time of designing. During the three years 1932 to 1934 the pressures recorded on the actual work had not exceeded an average of 75% of the theoretical. The reason was that there was always some silt deposit and in the months of high temperature and high heads, those deposits were generally of a clayey nature.

The outstanding contributions of this paper were :—

(*i*) The results on the prototype could be almost exactly reproduced on the scale model and the hydraulic model.

(*ii*) The problem of subsoil flow was susceptible of rigid mathematical treatment as the scale and electric analogy models gave identical results.

From the above and later results available with Mr. Harbans Lall and as brought out in the discussion it was evident that all seasonal variations could be explained by temperature or silt or by a combination of the two.

With those conclusions definitely proved, it was now possible to proceed with the analysis of various forms of floors by either of the two methods—the scale model or the electric analogy—checked mathematically where possible. The electric analogy method offered the quickest solution.

After detailed investigation of the various forms of foundation profiles it would be possible to lay down some simple rules for use in every day design. Major works would of course always have to be tested by models but for smaller works where facilities for such model work were lacking, those simple formulae would be most helpful.

The **author** replying to the discussions remarked that the discussions were clear and complete and required only a few closing comments.

The author said that Dr. N. K. Bose had been able to eliminate the effect of silt from the combined effect of silt and temperature. He explained that the model had completely reproduced the effect of silt and partially the effect of temperature. It was suggested that if Dr. Bose took Pipe No. 35 instead of Pipe No. 34 he would find that the effect of temperature was completely reproduced.

Mr A. N. Khosla compared the results obtained on the model with those on the prototype in detail and had attained a very good agreement. He suggested further experiments to be carried out on the residual head at the downstream end. Those experiments were already about to be started in the Irrigation Research Institute. It was clear from the discussions that the conclusions drawn in the paper were accepted. Engineers might say that it was easy to reproduce the results on the Panjnad model because the sand under the actual weir was of uniform grade, but if the geological conditions had been complex it would have been difficult for the experimenter to reproduce the results. A model of Khanki Weir Bay IV was examined. Under Bay IV of Khanki Weir there was a clay stratum 16′ below the crest. The upstream sheet pile pierced the clay while the downstream sheet pile was 2′ above it. All those conditions were reproduced in a Laboratory model. Pressures at three corresponding points on the model and the prototype were compared. It was found that the results agreed within one or two per cent. The conclusion that the model successfully reproduced the effect of complicated geological subsoil conditions was justified.

TABLE VI.

a water from the pump was allowed to flow in at the Upstream end at a temp. of =22·8°C.

perature of the water at the Downstream end in the beginning.=17·6°C.

6th February 1935.

pe No.	*Before starting the experiment.*	*1 hour and 30 minutes after.*		*3 hours and 15 minutes after.*		*4 hours and 15 minutes after.*		*5 hours and 15 minutes after.*		*6 hours and 15 minutes after.*		*7 hours and 15 minutes after.*		*8 hours and 15 minutes after.*		*9 hours and 15 minutes after.*		*10 hours and 15 minutes after.*	
	Temperature.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.
S. W.T.	..	22·8	..	22·5	..	22·4	..	22·7	..	22·8	..	22·0	..	21·5	..	21.5	..	21·5	..
34	17·5	21·2	97·15	21·2	97·27	21·2	97·36	21·2	97·36	21·2	97·15	21·1	97·10	21·0	97·26	20·8	..	20·7	97·42
35	17·5	20·1	89·26	20·4	89·85	20·4	89·70	20·6	90·06	20·6	89·75	20·7	89·78	20·4	89·80	20·4	..	20·3	89·92
36	17·5	19·0	78·88	19·4	79·70	19·5	79·71	19·7	79·76	19·8	79·39	20·0	79·61	19·8	79·40	19·8	..	19·8	79·53
31	17·8	18·9	70·52	20·0	72·37	20·0	71·89	20·2	71·73	20·2	71·77	20·4	71·51	20·2	71·53	20·1	..	20·0	71·45
32	17·7	18·9	72·54	19·4	74·19	19·5	73·66	19·6	73·41	19·6	73·19	19·9	73·08	20·0	73·46	19·8	..	19·9	72·87
33	17·6	19·6	78·55	19·3	79·08	19·4	78·57	19.6	78·47	19·7	78·35	19·8	78·26	19·8	78·26	19·8	..	19·6	78·13
24	18·0	18·5	65·06	18·6	66·36	18·7	65·90	18.9	65·85	19·0	66·24	19·2	66·02	19·2	66·21	19·2	..	19·2	66·04
26	17·8	18·0	60·28	18·2	61·25	18·6	60·92	18.5	69·92	18·6	60·85	19·0	60·87	19·0	60·90	19·0	..	19·0	60·81
23	18·0	18·0	58·77	18·1	59·43	18·3	58·84	18·4	59·25	18·5	59·23	18·9	59·04	19·0	59·09	18·9	..	18·9	58·88
21	18·0	18·0	51·97	18·3	52·66	18·4	52·39	18·5	52·59	18·6	52·52	18·8	52·21	18·9	52·18	19·0	..	18·9	52·23
20	18·0	18·0	52·64	18·0	53·39	18·0	52·97	18·2	52·13	18·4	53·26	18·7	53·01	18·8	53·02	18·7	..	18·7	52·92
16	18·2	18·0	43·53	18·1	44·02	18·2	43·61	18·3	44·07	18·5	44·01	18·6	43·36	18·7	43·61	18·6	..	18·8	43·67
13	18·2	18·2	39·64	18·2	40·30	18·2	39·87	18·1	40·13	18·4	39·94	18·5	40·02	18·6	39·77	18·6	..	18·4	39·68
15	17·8	17·8	36·91	17·8	37·44	18·8	37·10	17·8	37·36	17·9	37·68	18·0	37·35	18·0	37·30	18·0	..	18·0	37·47
10	18·0	18·0	31·75	18·0	32·27	18·0	31·80	18·1	32·31	18·4	32·23	18·4	32·04	18·6	31·95	18·6	..	18·4	31·97
12	17·9	18·0	24·65	17·8	25·27	17·9	24·82	18·0	25·13	18·0	25·04	18·2	25·14	18·2	24·87	18·2	..	18·2	24·69
7	17·8	17·8	9·72	18·0	9·94	17·9	9·84	18·0	9·94	18·1	9·79	18·4	9·91	18·3	9·68	18·2	..	18·3	9.83
9	17·8	17·8	19·99	17·8	20·39	17·8	20·23	17·8	20·28	18·0	20·14	18·2	20·13	18·2	20·02	18·1	..	18·0	20·21
D.S.W.T.	..	17·0	..	17·0	..	17·0	..	17·3	..	17·6	..	17·6	..	18·0	..	18·0	..	18·0	..

TABLE VII.

Temperature of the Inflowing water=28·8° C.

Temperature of the water at the Downstream end in the beginning=17·4° C.

9th February 1935.

Pipe No.	*Just before the temperature of the inflowing water was raised.*		*2 hours after the commencement of the experiment.*		*3 hours after.*		*4 hours after.*		*4 hours 45 minutes after.*		*6 hours and 38 minutes after.*		*7 hours and 5 minutes.*		*8 hours after.*		*9 hours after.*		*19 hours and 45 minutes after.*		*20 h mi*
	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature in C°.	Percentage effective pressure.	Temperature in C°.	Percentage effective pressure.	Temperature in
Room Temp.	17·8	..	17·8	..	18·7	..	18·8	..	19·0	..	18·8	..	18·8	..	18·8	..	18·7	..	18·0	..	17·
C.S.W.T.	17·5	..	27·0	..	28·2	..	28·8	..	28·6	..	28·6	..	28·7	..	28·8	..	28·7	..	28·8	..	28·
34	17·6	96·44	22·4	96·16	24·2	96·85	25·2	97·35	25·4	95·57	25·3	96·94	25·5	97·03	25·8	96·99	25·7	97·65	26·2	96·55	25·
35	17·6	88·57	19·9	89·20	22·1	89·71	23·1	90·26	23·8	89·46	24·0	89·58	24·2	89·63	24·4	89·62	24·5	90·54	24·6	89·41	24·
36	17·6	78·54	18·5	78·49	19·9	78·93	20·8	79·61	21·6	77·65	22·4	79·20	22·8	79·29	23·7	79·29	23·0	80·03	23·0	79·64	23·
31	17·8	70·00	19·4	70·47	20·8	71·19	21·8	71·74	22·3	71·12	22·9	71·60	23·0	71·84	23·3	71·74	23·3	72·63	23·4	71·49	23·
32	17·7	..	18·5	72·32	19·9	73·08	20·8	74·40	21·4	73·02	22·2	73·90	22·4	74·00	22·7	74·21	22·8	75·00	22·8	73·48	22·
33	17·8	77·69	18·4	77·59	19·7	77·92	20·6	78·42	21·4	77·43	21·1	78·24	22·3	78·47	22·5	78·51	22·7	79·19	22·7	79·11	22·
24	17·9	65·55	18·3	65·26	18·3	66·44	19·0	67·20	19·4	66·63	20·0	66·94	20·0	67·32	20·4	67·12	20·4	67·66	20·3	67·07	20·
26	17·9	59·55	18·0	59·21	18·4	59·95	18·8	60·63	19·0	60·23	19·7	60·13	19·8	60·88	20·2	60·63	20·2	61·07	20·4	60·68	20·
21	17·9	51·16	18·1	50·39	18·6	50·95	18·7	51·77	19·0	51·25	19·3	51·32	19·4	51·84	19·8	51·68	19·7	52·40	19·7	51·98	19·
23	17·9	57·75	18·0	57·23	18·4	57·84	18·6	58·83	18·9	58·25	19·4	58·43	19·6	59·08	19·7	58·65	19·8	59·44	19·7	58·96	19·
20	18·0	51·69	18·0	51·31	18·3	51·83	18·5	52·42	18·7	51·90	19·0	52·02	19·2	52·58	19·4	52·29	19·5	53·02	19·6	52·74	19·
16	18·0	42·55	18·1	42·70	18·3	43·24	18·5	43·78	18·7	43·36	18·8	43·60	18·9	43·90	19·1	43·73	19·1	44·21	19·2	43·67	19·
13	18·0	39·45	18·0	39·76	18·3	40·16	18·5	40·52	18·6	40·02	18·8	40·38	18·7	40·64	18·8	40·48	18·8	40·97	18·8	40·51	18·
15	17·6	37·54	17·9	37·49	18·0	37·98	18·0	38·30	18·3	37·71	18·4	38·02	18·2	38·46	18·4	37·98	18·4	38·36	15·5	38·07	18·
10	18·0	33·34	18·1	33·70	18·4	34·07	18·6	34·25	18·6	33·94	18·6	34·20	18·6	34·46	18·6	34·52	18·7	34·82	18·6	34·59	18·
12	17·9	24·92	18·0	24·61	18·1	24·85	18·4	25·12	18·4	24·19	18·5	24·99	18·6	25·38	18·6	25·17	18·7	25·48	18·5	25·15	18·
7	18·0	9·52	18·1	10·53	18·2	10·79	18·6	10·92	18·6	10·40	18·7	10·65	18·8	10·74	18·6	10·88	18·6	10·97	18·5	10·81	18·
9	17·8	20·43	18·0	20·46	18·0	20·84	18·4	21·02	18·4	20·43	18·6	20·88	18·5	21·10	18·5	21·02	18·5	21·11	18·4	20·83	18
D.S.W.T.	17·4	..	17·7	..	17·9	..	18·0	..	18·0	..	18·3	..	18·2	..	18·2	..	18·2	..	18·0	..	18·

TABLE VII.

Temperature of the Inflowing water=28·8° C.

Temperature of the water at the Downstream end in the beginning=17·4° C.

10th February 1935.

after.	*4 hours after.*		*4 hours 45 minutes after.*		*6 hours and 38 minutes after.*		*7 hours and 5 minutes.*		*8 hours after.*		*9 hours after.*		*19 hours and 45 minutes after.*		*20 hours and 45 minutes after.*		*21 hours and 45 minutes after.*		*22 hours and 45 minutes after.*		*30 hours after.*	
Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature in C°.	Percentage effective pressure.	Temperature in C°.	Percentage effective pressure.	Temperature in C°.	Percentage effective pressure.	Temperature in C°.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.
..	18·8	..	19·0	..	18·8	..	18·8	..	18·8	..	18·7	..	18·0	..	17·7	..	17·8	..	17·6	..	17·8	..
..	28·8	..	28·6	..	28·6	..	28·7	..	28·8	..	28·7	..	28·8	..	28·9	..	29·2	..	28·6	..	28·8	..
96·85	25·2	97·35	25·4	95·37	25·3	96·94	25·5	97·03	25·8	96·99	25·7	97·65	26·2	96·55	25·8	96·63	26·2	96·56	26·2	96·52	25·9	96·51
89·71	23·1	90·26	23·8	89·46	24·0	89·58	24·2	89·63	24·4	89·62	24·5	90·54	24·6	89·41	24·6	89·36	24·7	88·92	24·6	89·14	24·6	89·16
78·93	20·8	79·61	21·6	77·65	22·4	79·20	22·8	79·39	23·7	79·29	23·0	80·03	23·0	79·64	23·2	79·75	23·2	79·78	23·2	79·81	..	79·55
71·19	21·8	71·74	22·3	71·12	22·9	71·60	23·0	71·84	23·3	71·74	23·3	72·63	23·4	71·49	23·4	71·36	23·6	71·30	23·6	71·37	23·0	71·53
73·08	20·8	74·40	21·4	73·02	22·2	73·90	22·4	74·00	22·7	74·21	22·8	75·00	22·8	73·48	22·8	73·15	22·8	73·43	23·0	70·55	23·4	73·10
77·92	20·6	78·42	21·4	77·43	21·1	78·24	22·3	78·47	22·5	78·51	22·7	79·19	22·7	79·11	22·8	79·14	22·8	78·67	22·9	78·84	22·8	78·79
66·44	19·6	67·20	19·4	66·63	20·0	66·94	20·0	67·32	20·4	67·12	20·4	67·66	20·3	67·07	20·4	67·13	20·3	67·11	20·4	67·18	22·6	67·15
59·95	18·8	60·63	19·0	60·23	19·7	60·13	19·8	60·88	20·2	60·63	20·2	61·07	20·4	60·68	20·4	61·04	20·3	60·79	20·4	60·73	20·4	60·69
50·95	18·7	51·77	19·0	51·25	19·3	51·32	19·4	51·84	19·8	51·68	19·7	52·40	19·7	51·98	19·7	52·20	19·6	51·62	19·7	51·91	20·4	51·71
57·84	18·6	58·83	18·9	58·25	19·4	58·43	19·6	59·08	19·7	58·65	19·8	59·44	19·7	58·96	19·8	59·27	19·9	58·75	20·0	59·04	19·7	58·91
51·83	18·5	52·42	18·7	51·90	19·0	52·02	19·2	52·58	19·4	52·29	19·5	53·02	19·6	52·74	19·6	53·00	19·6	52·52	19·7	52·67	19·9	52·61
43·24	18·5	43·78	18·7	43·36	18·8	43·60	18·9	43·90	19·1	43·73	19·1	44·21	19·2	43·67	19·0	43·84	19·0	43·51	19·7	43·57	19·6	43·63
40·16	18·5	40·52	18·6	40·02	18·8	40·38	18·7	40·61	18·8	40·48	18·8	40·97	18·8	40·51	18·7	40·46	18·8	40·36	18·8	40·38	19·0	40·25
37·98	18·6	38·30	18·3	37·71	18·4	38·02	18·2	38·46	18·4	37·98	18·4	38·36	15·5	38·07	18·4	38·19	18·3	37·95	18·3	37·92	18·6	37·96
24·07	18·6	34·25	18·6	33·94	18·6	34·20	18·6	34·46	18·6	34·52	18·7	34·82	18·6	34·59	18·4	34·57	18·6	34·39	18·6	34·41	18·4	34·26
24·85	18·4	25·12	18·4	24·19	18·5	24·99	18·6	25·38	18·6	25·17	18·7	25·48	18·5	25·15	18·4	25·39	18·4	24·96	18·6	25·20	18·3	24·85
10·79	18·6	10·92	18·6	10·40	18·7	10·65	18·8	10·74	18·6	10·88	18·6	10·97	18·5	10·81	18·4	10·86	18·4	10·24	18·4	10·47	18·2	10·01
20·84	18·4	21·02	18·4	20·43	18·6	20·88	18·5	21·10	18·5	21·02	18·5	21·11	18·4	20·83	18·2	20·98	18·2	20·56	18·4	20·70	18·1	20·62
..	18·0	..	18·0	..	18·3	..	18·2	..	18·2	..	18·2	..	18·0	..	18·2	..	17·8	..	17·8	..	17·8	..

TABLE VIII.

Temperature of the Inflowing water = 12·0°C.

Temperature of the water at the Downstream end in the beginning = 17·4°C.

12th February 1935.

Pipe No.	*Before starting the experiment.*	*1 hour after.*		*2 hours after.*		*3 hours after.*		*4 hours after.*		*5 hours after.*		*5 hours and 45 minutes after.*		*6 hours and 45 minutes after.*		*7 hours and 10 minutes after.*	
	Temperature.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.
Room Temp.	..	18·4	..	18·4	..	18·8	..	18·8	..	19·0	..	19·0	..	19·0	..	19·1	..
U.S.W.T.	..	12·0	..	11·8	..	11·2	..	11·6	..	12·4	..	11·7	..	12·0	..	11·8	..
34	17·6	14·1	96·37	13·9	95·79	13·5	96·02	13·4	95·98	13·4	96·13	13·4	95·98	13·6	95·91	13·6	95·91
35	16·6	15·4	87·80	15·1	87·65	14·6	87·58	14·4	87·50	14·4	87·43	14·5	87·60	14·6	87·41	14·8	87·55
36	16·6	16·3	77·60	16·0	77·01	15·8	77·03	15·6	77·08	15·5	76·79	15·5	76·71	15·4	76·85	15·4	76·83
31	17·7	16·2	68·47	16·0	68·29	15·8	67·95	15·6	68·02	15·7	68·14	15·6	67·65	15·7	67·71	15·6	67·83
32	16·7	16·5	71·75	16·1	73·50	15·9	73·19	15·9	72·98	15·9	72·90	15·8	72·72	15·6	72·17	15·6	72·61
33	16·7	16·4	76·64	16·1	76·32	15·9	76·03	15·8	75·92	15·7	76·11	15·6	75·77	15·5	75·64	15·6	75·93
24	17·0	17·2	64·08	17·2	64·22	17·4	63·86	17·6	63·93	17·7	63·84	17·7	63·73	17·6	63·51	17·5	63·57
26	17·0	17·2	58·47	17·3	58·06	17·4	57·92	17·5	57·91	17·5	57·76	17·6	57·65	17·5	57·41	17·6	57·63
21	17·0	17·3	48·60	17·4	48·47	17·8	48·49	17·8	48·39	17·9	48·13	17·8	48·29	17·9	48·02	18·0	48·02
23	17·0	17·2	56·59	17·5	56·22	17·7	56·07	17·7	56·11	17·8	56·01	17·8	55·59	17·9	55·76	17·9	55·77
20	17·1	17·2	50·52	17·5	50·20	17·7	50·07	17·9	49·97	18·0	49·86	18·0	48·71	18·0	49·66	18·0	49·50
16	17·3	17·5	41·39	17·7	41·12	17·9	40·99	18·1	41·01	18·2	40·74	18·4	40·70	18·4	40·51	18·6	40·97
13	..	17·5	38·44	17·7	38·13	17·9	37·88	18·1	37·96	18·2	37·94	18·4	37·59	18·5	37·76	18·7	37·85
15	17·2	17·2	36·69	17·5	36·53	17·2	36·11	17·9	36·29	18·0	36·23	18·0	35·93	18·2	35·94	18·2	36·29
10	17·4	17·7	33·07	17·2	32·89	18·0	32·51	18·3	32·54	18·6	32·47	18·6	32·54	18·6	32·59	18·9	32·78
12	17·4	17·6	23·26	17·8	23·32	18·0	22·88	18·2	22·98	18·4	23·11	18·5	22·93	18·5	23·21	18·8	23·29
7	17·5	17·7	8·84	18·0	8·68	18·2	8·62	18·3	8·60	18·6	8·56	18·7	8·66	18·8	8·79	18·9	8·90
9	17·1	17·5	19·33	17·9	19·36	18·0	19·00	18·2	19·07	18·4	19·14	18·6	19·01	18·6	19·18	18·8	19·36
D.S.W.T.	..	17·4	..	17·7	..	17·9	..	18·0	..	18·2	..	18·3	..	18·5	..	18·6	..

TABLE IX.

Temperature of the Inflowing water=7·8°C.

Temperature of the water at the Downstream end=17·9°C.

13th February 1935.

Pipe No.	1 *hour after the commencement of the Expt.*		2 *hours after.*		3 *hours after.*		4 *hours after.*	
	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.	Temperature.	Percentage effective pressure.
Room Temp.	18·1	..	18·4	..	..	..	19·0	..
U.S.W.T.	12·4	..	9·5	..	7·8	..	7·8	..
34	14·5	95·83	13·2	95·78	11·1	95·96	10·4	95·84
35	16·4	87·34	15·4	87·09	13·7	87·13	13·0	86·76
36	18·4	77·12	17·2	76·57	16·1	76·47	15·2	76·06
31	17·6	68·66	16·6	67·96	15·6	67·68	15·0	67·20
32	18·4	72·24	17·3	70·34	16·4	69·92	15·6	70·87
33	18·3	76·24	17·2	75·84	16·4	75·65	15·5	75·27
24	19·0	64·95	18·7	64·09	18·4	63·80	18·2	63·26
26	19·2	58·63	19·0	57·85	18·6	57·56	18·4	57·19
21	18·8	49·82	18·7	49·25	18·6	48·73	18·6	48·34
23	19.0	57·08	18·9	56·24	18·7	56·04	18·6	55·69
20	19.0	51·03	18·9	50·49	18·8	49·97	18·7	49·60
16	18.8	42·16	18·6	41·48	18·6	41·32	18·7	40·66
13	18·3	39·04	18·4	38·59	18·4	38·43	18·5	37·86
15	18·1	37·10	18·2	37·51	18·2	36·53	18·3	36·06
10	18·2	33·54	18·2	33·11	18·3	32·99	18·4	32·56
12	18·1	24·55	18·2	24·03	18·3	23·56	18·5	23·81
7	18·2	9·85	18·2	9·57	18·4	9.53	18·3	9·23
9	18·0	20·43	18·0	20·21	18·1	20·04	18·2	19·70
D.S.W.T.	17·9	..	17·8	..	17·9	..	18·0	..

TABLE X.

Pipe No.	Mean Effective Pressure usual sand level.		Mean Effective Pressure, with Curved Scour.	
7	..	12·34	..	9·83
8	..	16·43	..	12·82
9	..	21·66	..	17·93
10	..	28·83	..	24·57
11	..	27·72	..	23·64
12	..	23·90	..	19·98
13	..	37·18	..	33·35
14	..	36·28	..	31·98
15	..	35·53	..	31·70
16	..	44·13	..	40·22
17	..	47·08	..	43·07
18	..	52·21	..	48·74
19	..	52·04	..	48·62
20	..	53·49	..	50·25
21	..	53·94	..	50·61
22	..	55·22	..	51·87
23	..	59·11	..	55·88
24	..	65·48	..	62·70
25	..	65·30	..	62·52
26	..	60·19	..	56·97
27	..	60·90	..	59·77
28	..	68·24	..	66·57
29	..	68·78	..	66·91
30	..	69·48	..	66·90
31	..	71·94	..	69·79
32	..	73·03	..	70·86
33	..	77·62	..	75·45
34	..	95·17	..	95·33
35	..	89·24	..	87·98
36	..	78·69	..	77·12
U.S.L.	..	..	..	

TABLE XI.

COMPARATIVE STATEMENT OF UPLIFT PRESSURES ON 1/50 SCALE MODEL OF PANJNAD WEIR & ITS PROTOTYPE.

Date.				17-9-33		12-8-34		5+ 9-9-34	24-1-34		29-11-33	18-4-34	23-3-34		11-4-34			27-6-34	16-10-32	19-10-33	14-3-34	Max: Recorded value of ϕ as percentage of Theoretical value.
Head=H		8.2	16.4	10.26	6.3	8.32	5.76	11.97	8.18	5.09	11.97	12.55	4.74	15.26	11.12	6.95	11.97	11.97	11.97	7.93	16.40	13.74	17.40	
Temp. (deb.)	U/S	Nil.	Nil.	1.6	1.2	2.6	1.6	4.2	2.8	2.9	4.2	2.8	2.9	2.9	5.7	2.8	4.2	4.2	4.2	2.4	..	3.8	2.2	
	D/S	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil.	Nil	Nil	Nil	Nil	Nil	Nil	..	..	..	
	River	About 78°	..	About 76°	89.5°	76°	87.5°	76.0°	85.5°	41.5°	58.3°	58.5°	76.0°	64.0°	76°	76.5°	58.3°	58.3°	38°.3	86°	..	74°	60°	
	Subsoil	.. 76°	..	.. 76°	85.0°	76°	82.0°	76°	78.5°	73.0°	76.1°	78.0°	74.5	71.5°	76°	74.5°	(a)	(b)	(c)	76°	..	79.5°	71°	
ϕ OR UPLIFT PRESSURES EXPRESSED AS PERCENTAGE OF HEAD (H).																					1932	1933	1934	

Pipe No.	1/50 Scale Model.	Electric analogy.	Scale Model.	Prototype.	Scale Model.	Prototype.	Scale Model.	Prototype.		Scale Model.	Prototype.			Scale Model.	Prototype.	Scale Model.	Scale Model.		Prototype.	PROTOTYPE. P	PROTOTYPE. ϕ	PROTOTYPE. P	PROTOTYPE. ϕ	PROTOTYPE. P	PROTOTYPE. ϕ	Col: 22 / Col: 2.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
34	94.01	93.00	79.12	80.00	68.04	72.00	38.20	65.50	87.8	45.10	74.90	80.2	81.9	51.59	84.0	51.59	47.77	47.57	71.40	12.49	76.1	10.11	80.8	14.45	83.1	81.0
35	87.12	86.50	73.21	71.00	64.55	62.91	54.73	53.0	55.45	41.90	42.60	41.00	44.2	48.28	48.1	48.28	36.02	44.40	31.00	9.12	55.6	6.56	47.9	8.05	46.2	64.0
36	76.12	76.50	67.24	64.40	57.42	57.42	48.31	45.99	47.74	36.80	35.80	37.30	32.9	42.39	42.7	42.39	39.10	39.05	39.00	7.93	48.3	5.98	43.4	6.53	49.0	63.4
33	75.79	75.00	66.04	64.50	56.93	56.87	48.00	47.50	48.50	36.84	37.10	34.90	36.9	42.25	41.8	42.25	38.88	38.78	29.30	8.37	49.2	5.94	43.2	6.75	38.8	64.9
32	71.35	71.00	61.60	62.10	53.71	55.22	45.39	45.30	46.42	34.75	35.20	34.80	34.9	40.20	40.4	40.20	37.01	36.91	26.00	7.83	47.7	5.96	43.3	6.44	37.0	66.6
31	70.39	70.50	60.41	60.80	53.61	53.30	45.24	45.00	45.49	34.60	35.30	32.90	34.2	39.59	40.0	39.59	36.85	36.92	28.00	7.75	47.2	6.02	43.9	6.30	36.2	67.0
30	68.63	67.30	60.18	42.4	51.60	59.2	43.55	51.7	46.5	33.62	38.5	37.80	34.1	38.76	46.1	38.76	35.34	35.63	27.20	7.96	48.5	6.43	46.8	6.39	36.7	70.7
29	67.99	66.30	58.36	60.00	50.56	52.75	42.70	42.80	44.74	32.99	34.00	32.00	33.5	38.03	39.0	38.03	34.84	34.82	27.30	7.60	46.3	5.70	41.5	6.17	35.5	68.1
28	67.64	66.70	58.37	58.40	50.73	51.37	42.79	43.20	43.08	32.86	33.70	33.00	33.1	38.08	38.4	38.08	34.85	34.79	27.10	7.54	46.0	5.69	41.3	6.12	35.2	68.0
27	66.72	66.25	53.45	53.30	50.21	52.30	42.29	43.10	45.20	32.21	32.90	32.50	32.5	37.81	38.0	37.81	34.68	34.48	26.30	6.48	39.5	5.53	40.2	5.99	34.5	66.0
24	63.64	64.00	55.83	59.00	48.50	52.75	40.20	42.80	42.11	31.25	34.00	31.20	32.7	36.06	39.6	36.06	33.10	33.03	26.50	7.34	44.7	5.89	42.1	5.97	34.3	70.5
25	64.46	62.50	55.40	76.80	48.52	59.70	40.95	60.5	62.6	31.64	42.5	49.8	32.9	36.34	56.3	36.51	33.36	33.07	25.50	8.10	49.4	7.11	51.7	6.26	36.0	76.6
26	60.60	59.20	51.06	70.00	45.31	55.90	38.11	54.8	39.85	29.54	33.8	29.10	31.0	34.13	39.3	34.13	31.26	31.01	24.40	7.00	42.6	5.60	40.7	5.74	32.9	71.0
23	58.73	58.30	49.76	52.50	44.53	46.43	37.38	38.90	38.91	28.79	30.20	29.10	29.1	33.25	34.0	33.25	30.31	30.50	24.00	6.84	41.7	5.18	37.7	5.40	31.1	71.0
22	55.45	55.00	46.80	49.00	42.12	43.68	35.38	37.00	36.84	27.70	28.80	26.90	27.6	31.72	32.5	31.72	28.95	29.48	22.70	6.57	40.1	4.95	36.0	5.10	29.3	72.3
21	54.24	53.80	48.74	47.60	41.12	42.58	34.67	35.70	34.91	26.82	28.20	26.40	26.8	30.57	31.1	30.57	28.31	28.36	22.30	6.46	39.3	4.90	35.7	4.94	28.4	72.5
18	53.00	54.20	44.36	45.70	40.03	40.03	33.50	33.70	31.21	26.07	27.40	25.10	25.8	29.89	30.4	29.89	27.52	28.35	21.70	6.33	38.6	4.74	34.5	4.76	27.3	72.8
19	53.03	53.10	43.95	45.40	40.49	39.60	33.90	35.20	36.9	26.32	27.20	23.20	24.9	30.18	30.8	30.18	27.94	27.81	20.00	5.99	36.5	4.8	34.9	4.59	26.4	68.8
20	51.05	54.70	44.88	..	40.85	..	34.28	..	..	26.70	..	..	..	30.32	..	30.32	28.16	28.24	..	..	..	..	..	..	..	..
17	48.14	47.80	36.53	44.30	36.37	39.01	31.01	33.10	33.08	23.94	26.20	24.20	24.5	27.75	29.2	27.75	25.39	25.29	20.80	5.90	36.5	4.37	33.2	4.53	26.1	75.9
16	45.67	45.80	38.57	42.00	35.00	37.00	29.58	31.70	31.77	22.79	27.30	23.20	23.5	26.21	27.8	26.21	24.15	23.96	20.00	5.81	35.4	4.41	32.1	4.24	24.9	77.4
13	39.37	40.70	33.51	35.10	30.20	31.87	25.83	25.90	28.20	18.87	21.50	20.10	19.2	22.98	25.7	22.98	21.00	20.85	17.00	4.91	30.9	3.76	27.4	3.55	20.2	76.1
14	34.21	40.50	32.88	36.00	29.74	32.69	25.58	..	28.38	19.78	22.10	20.30	19.9	22.90	24.8	22.90	20.96	20.72	16.40	5.03	30.7	3.88	28.2	3.68	21.1	78.0
15	38.85	39.40	32.50	34.30	28.72	31.80	25.08	28.70	29.9	19.52	21.70	19.90	19.6	22.40	23.8	22.40	20.70	20.59	15.80	4.88	29.8	3.79	27.6	3.59	20.6	76.6
10	30.58	31.00	26.29	30.30	24.30	25.09	21.60	22.90	22.93	16.14	18.90	16.40	17.3	18.99	21.3	18.99	17.14	17.15	14.50	4.13	25.2	3.18	23.1	3.17	18.2	82.3
11	30.77	30.50	23.64	30.00	23.43	26.2	20.71	21.20	24.9	13.78	18.40	16.90	16.0	18.42	20.0	18.42	16.64	16.60	13.70	4.18	25.5	3.23	27.5	2.98	17.1	82.4
12	26.43	27.50	22.20	28.10	19.25	29.7	17.26	26.8	32.6	13.12	22.10	21.8	18.4	15.10	26.3	15.16	13.85	13.98	13.50	4.78	23.1	3.02	28.5	3.42	19.6	87.5
9	21.02	23.00	19.30	23.8	17.67	20.62	15.69	16.00	20.9	12.19	15.10	13.80	12.8	14.20	15.8	14.20	12.87	12.86	10.50	3.44	20.9	2.62	19.1	2.42	13.0	90.9
8	16.79	14.30	14.80	14.80	14.22	11.81	12.71	8.00	12.9	10.16	10.10	8.80	7.6	11.48	9.5	11.48	10.53	10.47	5.00	1.11	6.9	1.77	12.2	1.17	8.4	41.6
7	10.94	8.00	10.79	11.60	10.37	7.60	10.24	1.00	11.6	8.15	8.44	8.80	6.7	9.24	9.1	9.24	8.47	8.41	3.00	1.56	9.3	1.47	10.7	1.26	7.2	87.1

Pipes 34, 25 & 12 of the Model & Prototype differ widely throughout.

Pipe 30 differs somewhat. Pipe 20 in the Prototype is inoperative.

(a) Table V 40 minutes from Beginning of Experiment.
(b) " " 140 " " " " "
(c) " " 120 " After process Reversed.

P = Indicated pressure.
= W. L. In pipe Minus Tail W. L.
H = Total Head
ϕ = P/H × 100

TABLE XII.

Effect of Temperature—Gradient on Pressure—Gradient.

No.	Time of observations.	*U/S A.*		*Pipe I B.*		*Pipe II C.*		*Pipe III D.*		*D/S.*	*Head in D.* / Head in C.
		Head over D/S.	Temp.	Head over D/S.	Temp.	Head over D/S.	Temp.	Head over D/S.	Temp.	Temp.	
1	3/10 P.M.	37·55 CM	17·4°C	30·95 CM	17·4°C	17·5 CM	17·4°C	4·85 CM	17·8°C	17·6°C	·277
2	3/27 P.M.	37·55 CM	14·4°	30·55 CM	16·4°	17·30 CM	17·4°	4·85 CM	17·8°	17·6°	·278
3	3/32 P.M.	37·55 CM	11·6°	30·45 CM	14·4°	16·90 CM	17·2°	4·65 CM	17·8°	17·6°	·275
4	3/37 P.M.	37·55 CM	10·6°	30·25 CM	12·7°	16·70 CM	15·8°	4·45 CM	17·8°	17·6°	·266
5	3/42 P.M.	37·55 CM	9·8°	30·25 CM	11·7°	16·60 CM	14·4°	4·35 CM	17·0°	17·6°	·262
6	3/47 P.M.	37·55 CM	9·6°	30·45 CM	10·7°	16·55 CM	13·3°	4·25 CM	16·0°	17·3°	·257
7	3/52 P.M.	37·55 CM	10·0°	30·35 CM	10·5°	16·70 CM	12·6°	4·35 CM	15·1°	16·7°	·260
8	3/57 P.M.	37·55 CM	10·0°	30·45 CM	10·8°	16·80 CM	12·3°	4·45 CM	14·5°	16·0°	·271
9	4/2 P.M.	37·55 CM	9·6°	30·55 CM	10·7°	16·80 CM	12·2°	4·55 CM	14·0°	15·4°	·271
10	4/7 P.M.	37·55 CM	9·9°	30·55 CM	10·6°	16·90 CM	12·2°	4·65 CM	14·0°	15·0°	·275

Note.—Cold water passed through the Jacket at 3 16 U/S. Temp. effected at 3/22 and Pipe I, Temp. at 3/25.

DIAGRAM VII

Ⓣ SHOWS THE POSITION OF THERMOMETER POINTS

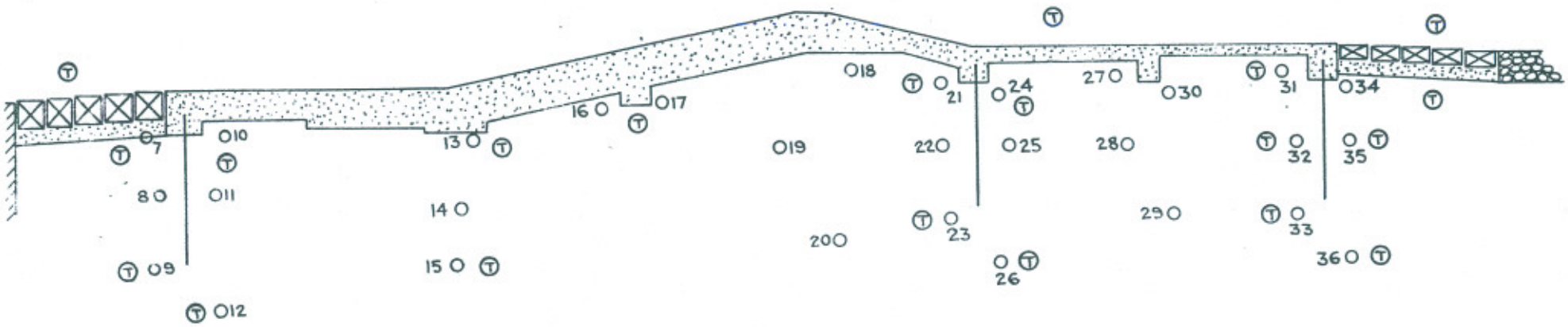


DIAGRAM VIII

TEMPERATURES UNDER PANJNAD WEIR MODEL

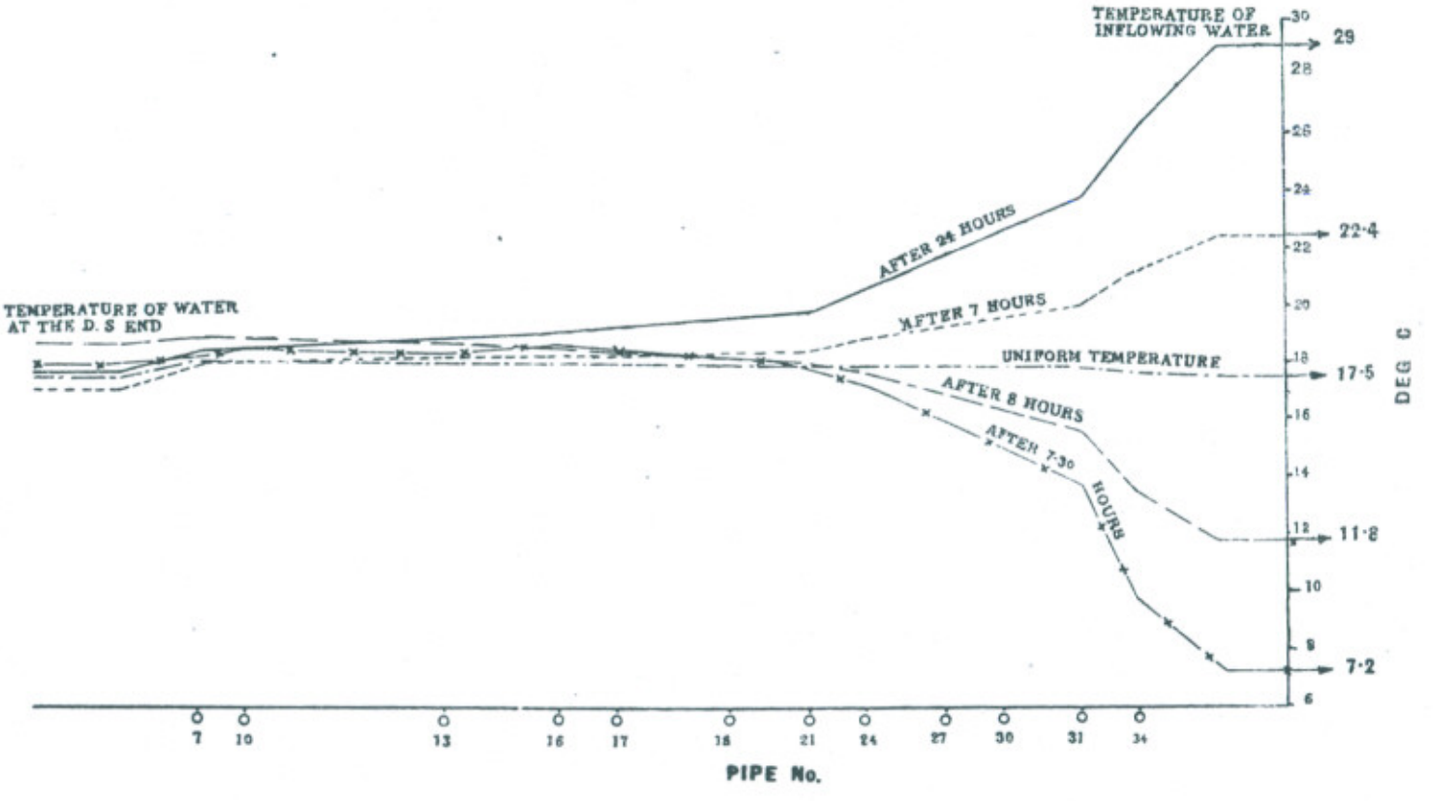


DIAGRAM. IX

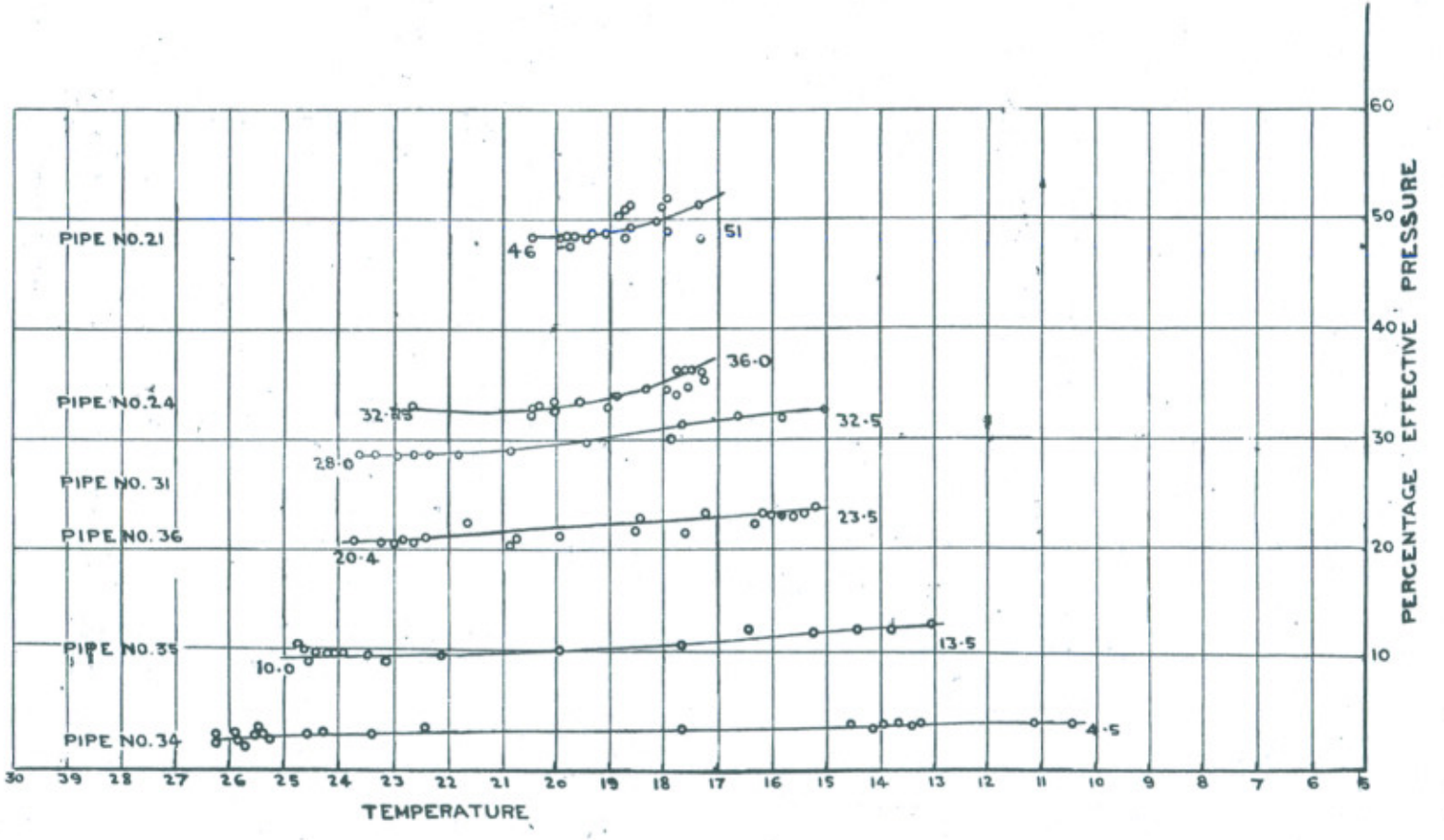

PIPE NO.21
PIPE NO.24
PIPE NO. 31
PIPE NO. 36
PIPE NO.35
PIPE NO.34
46
51
36·0
32·5
32·25
28·0
20·4
23·5
10·0
13·5
4·5
PERCENTAGE EFFECTIVE PRESSURE
TEMPERATURE
60
50
40
30
20
10
30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5

DIAGRAM X

HYDRAULIC GRADIENTS UNDER PANJNAD WEIR MODEL AT DIFFERENT TEMPERATURES OF THE INFLOWING WATER

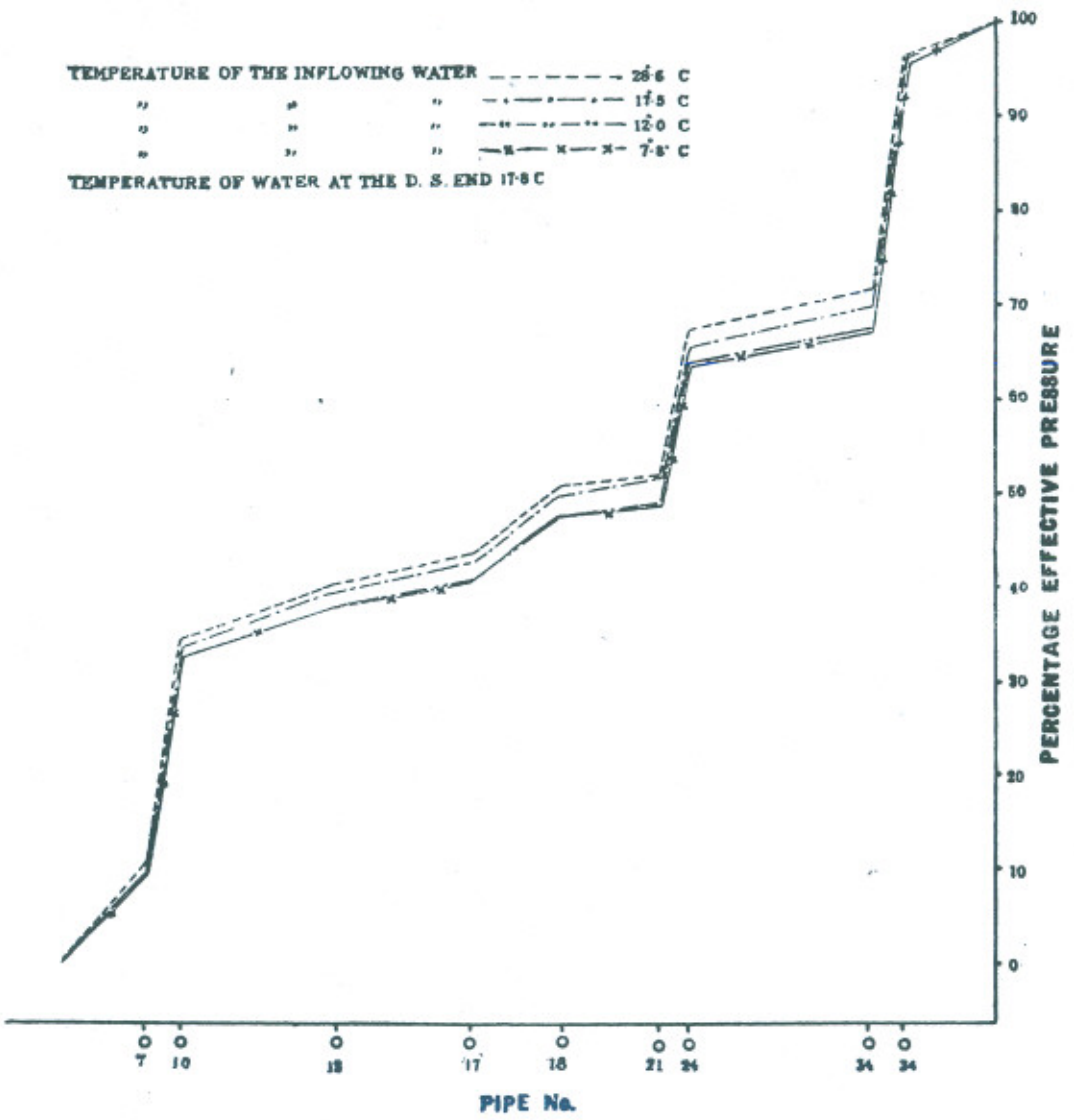


DIAGRAM XI.

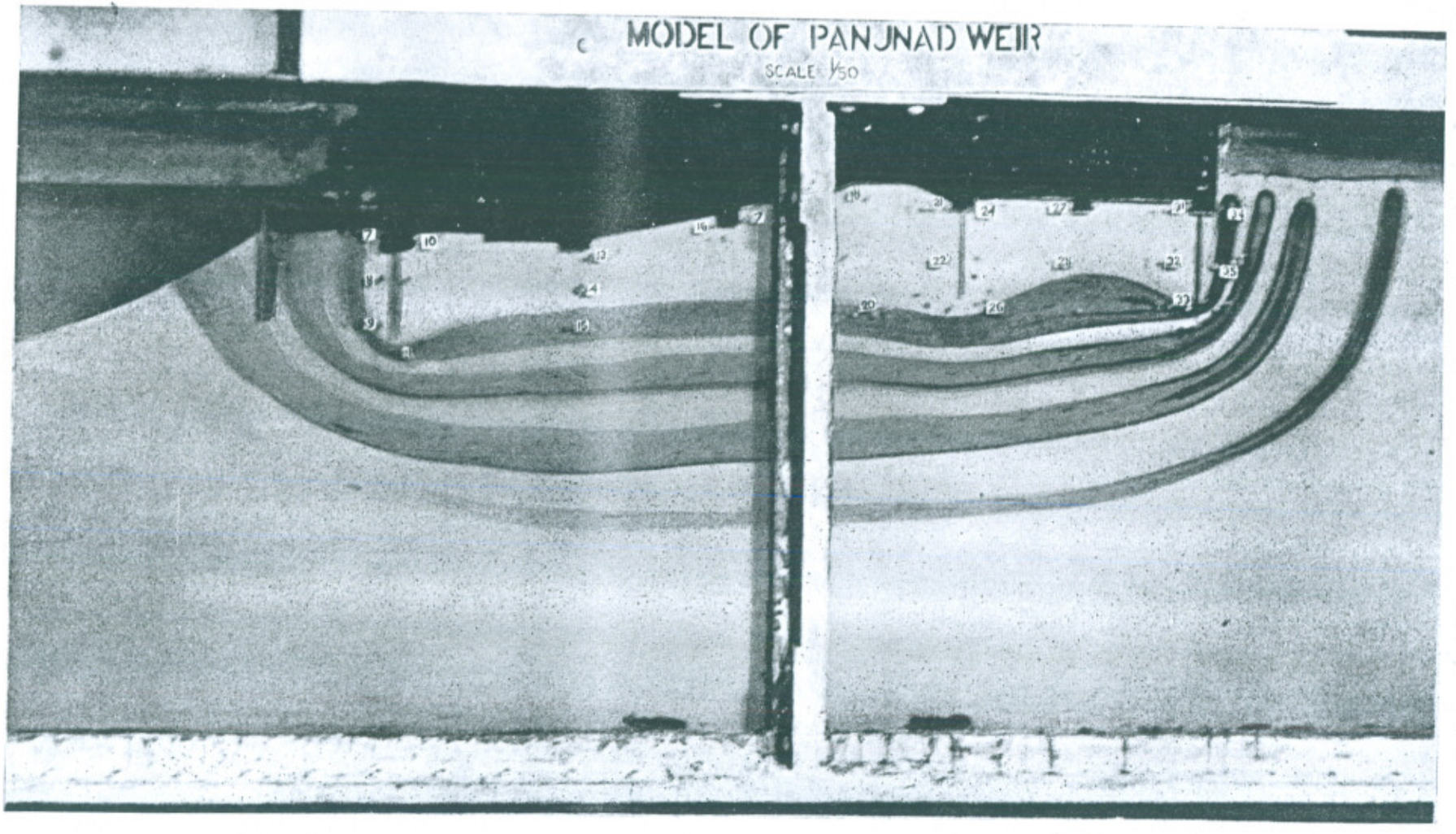
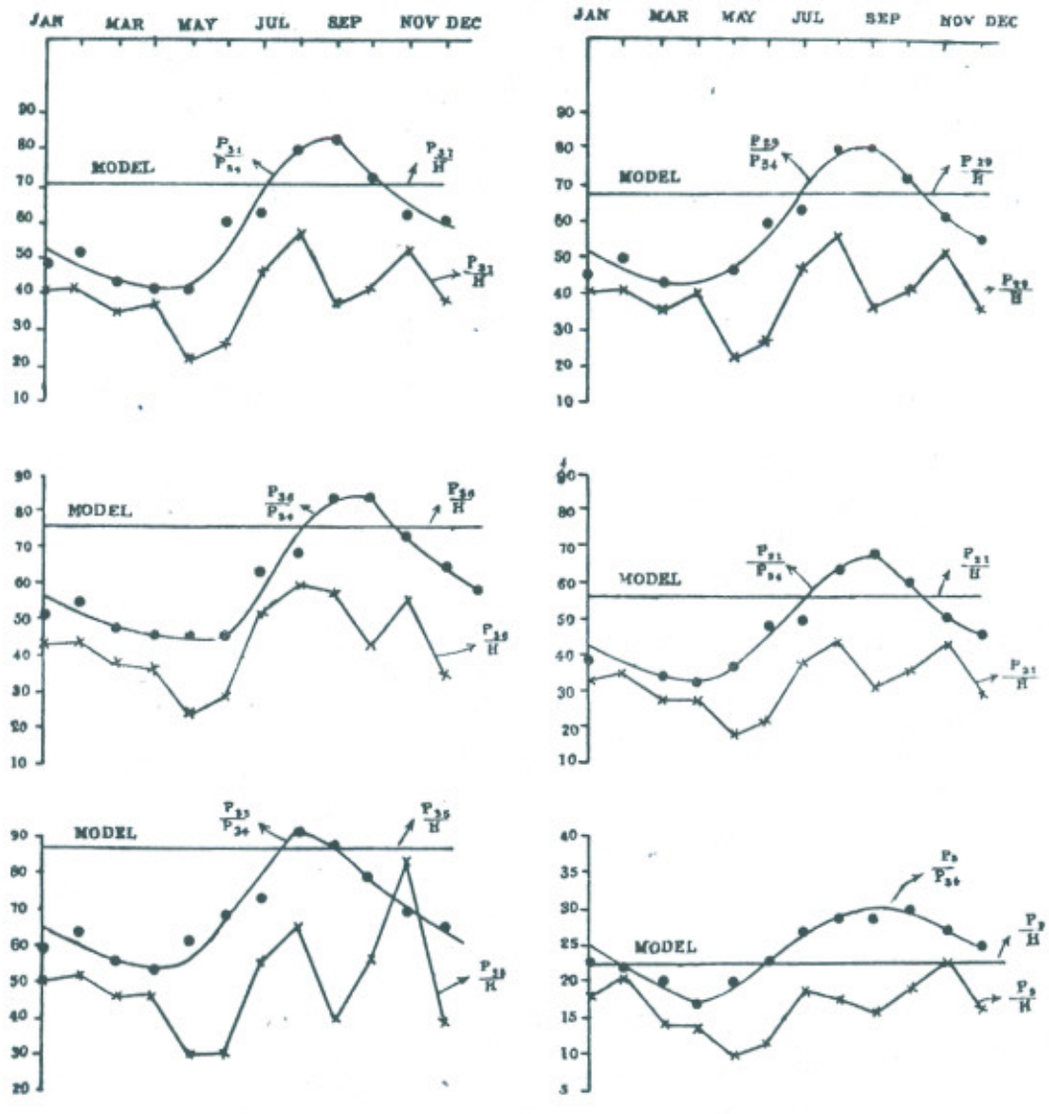


DIAGRAM XII



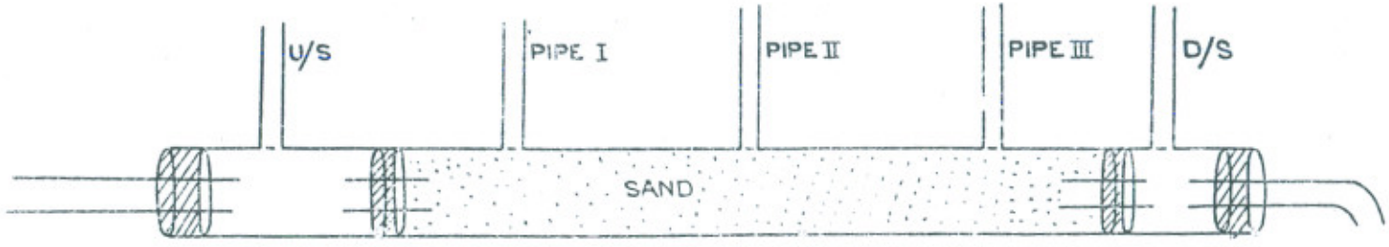


DIAGRAM. XIII

DIAGRAM SHOWING RELATIVE EFFECTIVENESS OF VERTICAL AND HORIZONTAL CONTACTS PANJNAD WEIR (1/50) MODEL AND PROTOTYPE.

