COLORADO STATE UNIVERSITY

FORT COLLINS, COLORADO

DEPARTMENT OF CIVIL ENGINEERING

December 10, 1958

Mr. C. G. Cooley
Cooley Gravel Company
6101 Lowell Boulevard
Denver 21, Colorado

Subject: Annular Jet Inducer

Dear Sir:

We have completed the study on the annular jet inducer and the results are presented herein. The objectives were to determine the following:

(1) The practicability of using this type of device for transporting sand and gravel.
(2) An effective jet angle, where the jet angle is defined as the angle the side of the reducing cone makes with the wall of the pipe.
(3) Whether the annular jet is more effective than the central jet, or whether a combination of the two jets is more desirable.
(4) What combination of pressure and discharge through the annular jet is most effective for maximum inducing capability.
(5) Effect of discharge head on the capacity of the annular jet inducer.

The arrangement of test equipment is shown schematically in Exhibit 1 of the enclosures. The jet water was supplied from an 8-inch high head 60 H.P. turbine pump. The quantity of water pumped and discharged through the annular jet was measured by an orifice installed in the 8-inch line leading to the annular jet chamber. This orifice had been previously calibrated. A pressure gauge was installed in the annular jet chamber to enable measurement of operating pressures. Gauges were also installed in both the discharge and suction sides of the annular jet. A valve was installed in the discharge line of the annular jet to permit testing effects of various discharge heads.

The discharge line extended to an elevated box where a Cipolletti weir was installed to measure the flow through the system. Thus, the quantity of water induced by the annular jet was determined by the difference between total discharge and jet discharge.

The investigation consisted of testing 3 jets with angles of 5°, 12.5°, and 25°. For each jet the opening and pressure were varied along with various discharge heads. The opening was adjusted by moving the lower portion of the jet. See Exhibit 2 for sectional views of the jets.

Measurements of the total quantities of water passed through the annular jet inducer were made and an optimum opening was determined for each jet angle. The discharge head was determined from readings of the pressure gage in the discharge line. When the best jet angle was found, and the optimum jet opening determined, tests were made of the annular jet in transporting sand and gravel. These latter tests were made by placing the material in the supply pit and controlling the suction pipe so that an optimum operating position was determined by trial.

The results of the study are shown graphically and in tabular form in Exhibits 3 to 8. It is well to mention here, before proceeding further, that the tests also included studies of the central jet alone and in conjunction with the annular jet. The central jet used, which was $\frac{13}{16}$ inch in diameter could not induce water by itself and proved to be of no assistance to the performance of the annular jet. This was true both for pumping water and pumping sand and gravel. Subsequent analysis reported hereafter, therefore, excludes results with the central jet. Significant data is shown in tabular form in Exhibit 3.

Exhibit 4 shows that for each of the three jets tested, there exists an optimum jet opening in relation to the cross sectional area of the suction pipe such that the quantity of water induced by the annular jet is a maximum for a given jet discharge. The first term is arbitrarily designated as the jet area ratio A_s/A_j, where A_s is the cross-sectional area of the suction pipe and A_j is the effective annular jet opening. The second term will be termed the discharge ratio Q_s/Q_j, where Q_s is the quantity of jet induced water through the suction pipe and Q_j is the quantity of water through the annular jet. In restating, there is an optimum jet opening which produces the maximum discharge ratio for each of the three jets. Note that the value of the jet area ratio for all three jets are very nearly the same. Another significant result shown here is that the smaller angle provides the best results, which in this instance is the 5° jet.

The variation of the discharge ratio with the jet area ratio and jet pressure is shown in Exhibit 5. The significant thing to note here is that as the jet pressure increases the discharge ratio also increases for a given jet, and that the maximum discharge ratio occurs for a nearly constant jet area ratio of about 11.5.

Exhibit 6 is a graphical representation of the effect of total head and jet pressures on the discharge ratio. The values of total head given here are model values and are included as part of the results to indicate the effect of increasing discharge head on the inducing capacity of the annular jet. Exhibit 7 indicates the relationship of maximum discharge ratio with jet angles for jet operating pressures of 95 p.s.i.

We can conclude from the results that the most effective jet angle of those tested was the 5° jet, with which a discharge ratio slightly greater than 0.75 was obtained with an operating jet pressure of about 94 p.s.i. and jet area ratio of 11.5. If the jet pressure is increased, it would be reasonable to assume that a larger discharge ratio can be attained. There will be a maximum practical limit however, due to the capacity of the pumping unit supplying water to the jet or to development of vapor pressures within the annular jet.

It has also been noted that the best performance is achieved with a certain jet area ratio, and that variation of the jet pressure does not have significant effect on this value. Therefore, the inducing capacity of the annular jet can be controlled by the annular jet discharge and the unit will operate at near peak performance for a wide range of jet pressures. There is a value of total head for which the annular jet will not induce any water for a given operating jet pressure. In the model, the maximum was 29 feet for a jet pressure of 94 p.s.i. The total head that the system can operate against can be expected to be much larger for the field installation because of the higher jet pressures involved.

Tests were made to determine the practicability of transporting sand and gravel with the annular jet, and in an effort to keep testing to a practical and justifiable limit, only the 5° annular jet was used at jet openings near optimum as previously determined. The results are shown in tabular form in Exhibit 8. It is well to note here that although a scale relationship between model and prototype with respect to gravel transport cannot be stated with confidence, it can be expected that in the prototype greater quantities and concentrations can be expected because the specific gravity of gravel in both model and prototype is approximately the same.

Results from these tests indicated logically that greater quantities of material can be pumped if the material is graded than if it is uniform in size. There was less quantity of 3/4-inch gravel transported than there was of sand and 3/4-inch gravel when mixed together. The concentration in the discharge line of the annular jet for tests with 3/4-inch gravel only was approximately 10 percent and for sand mixed with 3/4-inch gravel about 14 percent.

Finally, to describe most aptly what happens when the annular jet is submerged under water, see Exhibit 9. This is a schematic representation of an annular jet that in case 1 is above water and in case 2 is submerged any distance x, say 36 feet. Keeping in mind that the motive force inducing water through the suction pipe is the difference in pressure that exists outside the suction pipe and inside affected by the annular jet, so long as the jet conditions of opening and pressure are maintained the same in case 1 as in case 2, and that in case 1 vapor pressures are not approached in the suction pipe, the quantity of water through the system in case 1 will be the same as in case 2. While it is true that a greater positive head exists at the entrance to the suction pipe in case 2, the motive force, or the differences in pressures, remains the same as in case 1 because the annular jet is capable of effecting only that same difference because the discharge pressure increases as well. Therefore, submerging the annular jet will not increase the production rate of the unit. However, by submergence and in specific application to your use, you can expect more trouble-free performance because the shorter suction pipe gives less chance to clog and the greater positive head at the annular jet reduces the possibility of cavitation.

I sincerely hope that this study has answered some of your immediate questions, and my only regret is that sufficient time could not be allowed to approach this problem from a more fundamental viewpoint.

Very truly yours,

S. Karaki

S. Karaki
Assistant Civil Engineer

SK:dj

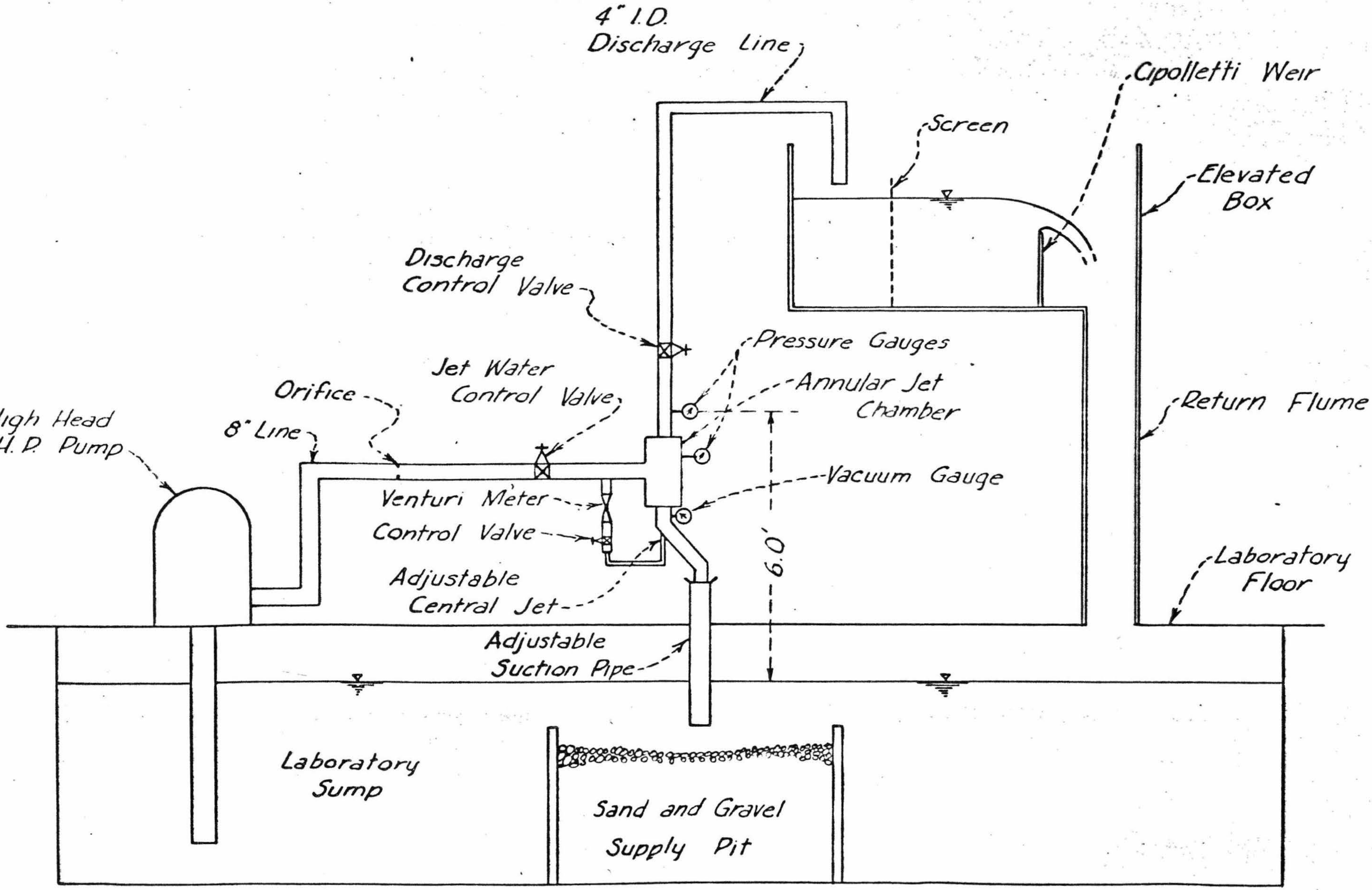
Enclosures 9

cc: Mr. John Meckenstock

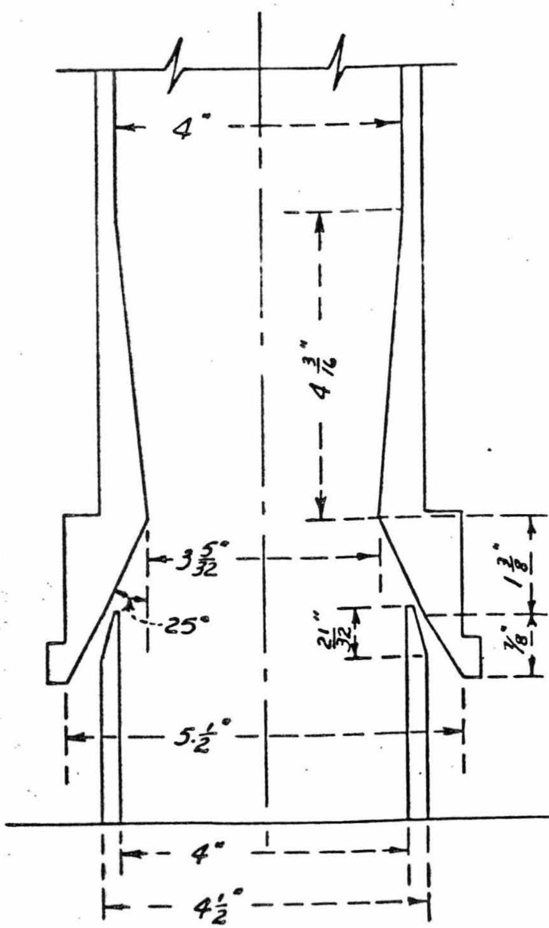
Approved

A. R. Chamberlain

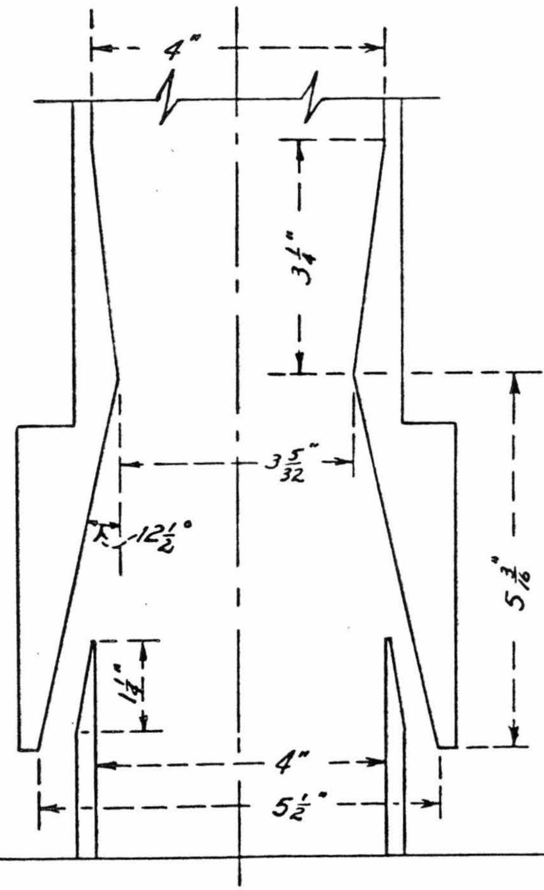
A. R. Chamberlain, Chief
Civil Engineering Section



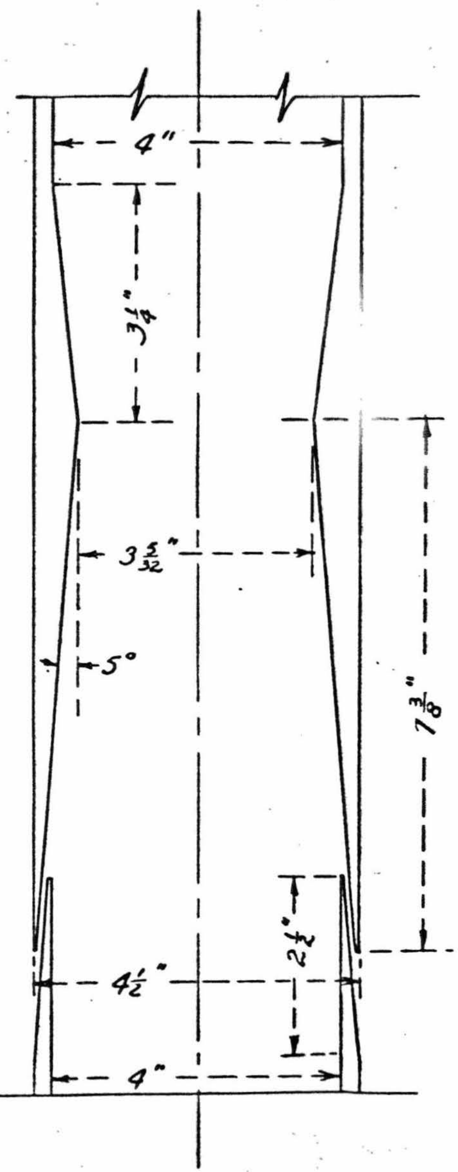
Schematic Diagram of Test Equipment



25° JET



12½° JET



5° JET

EXHIBIT C

TESTS WITH WATER ONLY

Run No.	Measured Data							Calculated Quantities			
	α Jet Angle	A_j Jet Area	P_j Jet Pres.	Q_j Jet Disch.	Q_t Total Discharge	P_d Discharge Pressure	H_s Maximum Suction	Q_s Induced Discharge	Q_s/Q_j Discharge Ratio	A_s/A_j Jet Arch Ratio	H_t Total Head
	Degrees	Ft^2	p.s.i.	g.p.m.	g.p.m.	p.s.i.	in. Hg.	g.p.m.			Ft
4	5	0.0046	102	207	216	2.5	—	9	0.0435	18.9	11.8
7	5	.0050	102	229	260	2.5	—	31	.135	17.4	11.8
11	5	.0060	100	260	350	3.0	11	90	.346	14.5	12.9
14	5	.0060	90	251	312	3.0	—	61	.243	14.5	12.9
16	5	.0060	80	251	265	2.5	—	14	.056	14.5	11.8
17	5	.0060	70	220	220	2.2	—	0	0	14.5	11.1
18	5	.0065	98	283	425	4.0	14	142	.502	13.4	15.2
22	5	.0065	90	276	395	3.5	—	119	.431	13.4	14.1
25	5	.0065	80	260	350	3.5	—	90	.346	13.4	14.1
27	5	.0065	70	238	295	3.0	—	57	.239	13.4	12.9
29	5	.0070	97	300	500	5.0	17	200	.667	12.5	17.5
34	5	.0070	90	291	475	4.75	—	184	.632	12.5	17.0
38	5	.0070	80	278	432	4.0	—	154	.554	12.5	15.2
42	5	.0070	70	251	360	3.5	—	101	.402	12.5	14.1
44	5	.0075	95	314	550	6.0	20	236	.751	11.6	19.9
49	5	.0075	85	296	500	5.0	—	204	.689	11.6	17.5
53	5	.0075	75	278	445	4.5	—	167	.600	11.8	16.4
56	5	.0075	65	269	395	4.0	—	126	.468	11.8	15.2
60	5	.0080	94	336	590	6.5	22.5	254	.756	10.9	21.0
61	5	.0080	94	336	540	7.5	20	204	.607	10.9	23.3
62	5	.0080	94	336	490	8.5	18	154	.458	10.9	25.6
63	5	.0080	94	336	430	9.5	13	94	.280	10.9	28.0
65	5	.0080	85	322	540	6.0	19	218	.677	10.9	19.9
66	5	.0080	85	322	475	7.0	16.5	153	.475	10.9	22.2
67	5	.0080	85	322	410	8.0	14.0	88	.273	10.9	24.5

TESTS WITH WATER ONLY

Run No.	Measured Data							Calculated Quantities			
	α Jet Angle	A_j Jet Area	P_j Jet Pres.	Q_j Jet Disch.	Q_t Total Discharge	P_d Discharge Pressure	H_s Maximum Suction	Q_s Induced Discharge	Q_s/Q_j Discharge Ratio	A_s/A_j Jet Arch Ratio	H_t Total Head
	Degrees	Ft^2	p.s.i.	g.p.m.	g.p.m.	p.s.i.	in. Hg.	g.p.m.			Ft
68	5	0.0080	85	322	345	9.0	7.5	23	0.071	10.9	26.8
69	5	.0080	75	302	490	5.0	15.5	185	.607	10.9	17.5
70	5	.0080	75	305	440	6.0	14.0	135	.442	10.9	19.9
71	5	.0080	75	305	375	7.0	11.0	70	..230	10.9	22.2
73	5	.0080	65	286	435	4.5	12.5	149	.520	10.9	16.4
74	5	.0080	65	286	345	5.75	9.0	59	.206	10.9	19.3
76	5	.0088	92.5	369	620	7.2	22.5	251	.707	9.9	22.6
81	5	.0088	82.5	351	580	6.5	20	229	.653	9.9	21.0
86	5	.0088	72.5	327	515	5.5	16.5	188	.575	9.9	18.7
91	5	.0088	62.5	310	460	4.75	13.0	150	.484	9.9	17.0
94	5	.0094	91.5	390	660	8.0	23.0	270	.692	9.3	24.5
98	5	.0094	80	369	595	7.0	21.0	226	.613	9.3	22.2
102	5	.0094	70	347	535	6.0	16.5	188	.542	9.3	19.9
106	5	.0099	90	410	680	8.5	23.0	270	.658	8.8	25.6
2	12.5	.0051	98	240	285	2.0	6.5	45	.187	17.1	10.6
3	12.5	.0056	97	269	380	3.0	10.0	111	.412	15.5	12.9
28	12.5	.0065	95	315	485	4.0	14	170	.540	13.4	15.2

TESTS WITH WATER ONLY

Run No.	Measured Data							Calculated Quantities			
	α Jet Angle	A_j Jet Area	P_j Jet Pres.	Q_j Jet Disch.	Q_t Total Discharge	P_d Discharge Pressure	H_s Maximum Suction	Q_s Induced Discharge	Q_s/Q_j Discharge Ratio	A_s/A_j Jet Arch Ratio	H_t Total Head
	Degrees	Ft^2	p.s.i.	g.p.m.	g.p.m.	p.s.i.	in. Hg.	g.p.m.			Ft
40	12.5	.0075	92	365	585	5.5	—	220	.602	11.6	18.7
52	12.5	.0086	90	401	640	7.0	19	239	.596	10.1	22.2
70	12.5	.0101	84	458	675	8.0	21	217	.485	8.6	24.5
80	12.5	.0112	82	502	730	9.5	22	228	.454	7.8	28.0
1	25	.0079	96	393	589	5.5	—	196	.498	11.0	18.7
17	25	.0097	92	479	688	8.0	—	209	.436	9.0	24.5
35	25	.0118	87	572	786	9.5	—	214	.374	7.4	28.0

VARIATION OF DISCHARGE RATIO WITH JET ANGLE & AREA

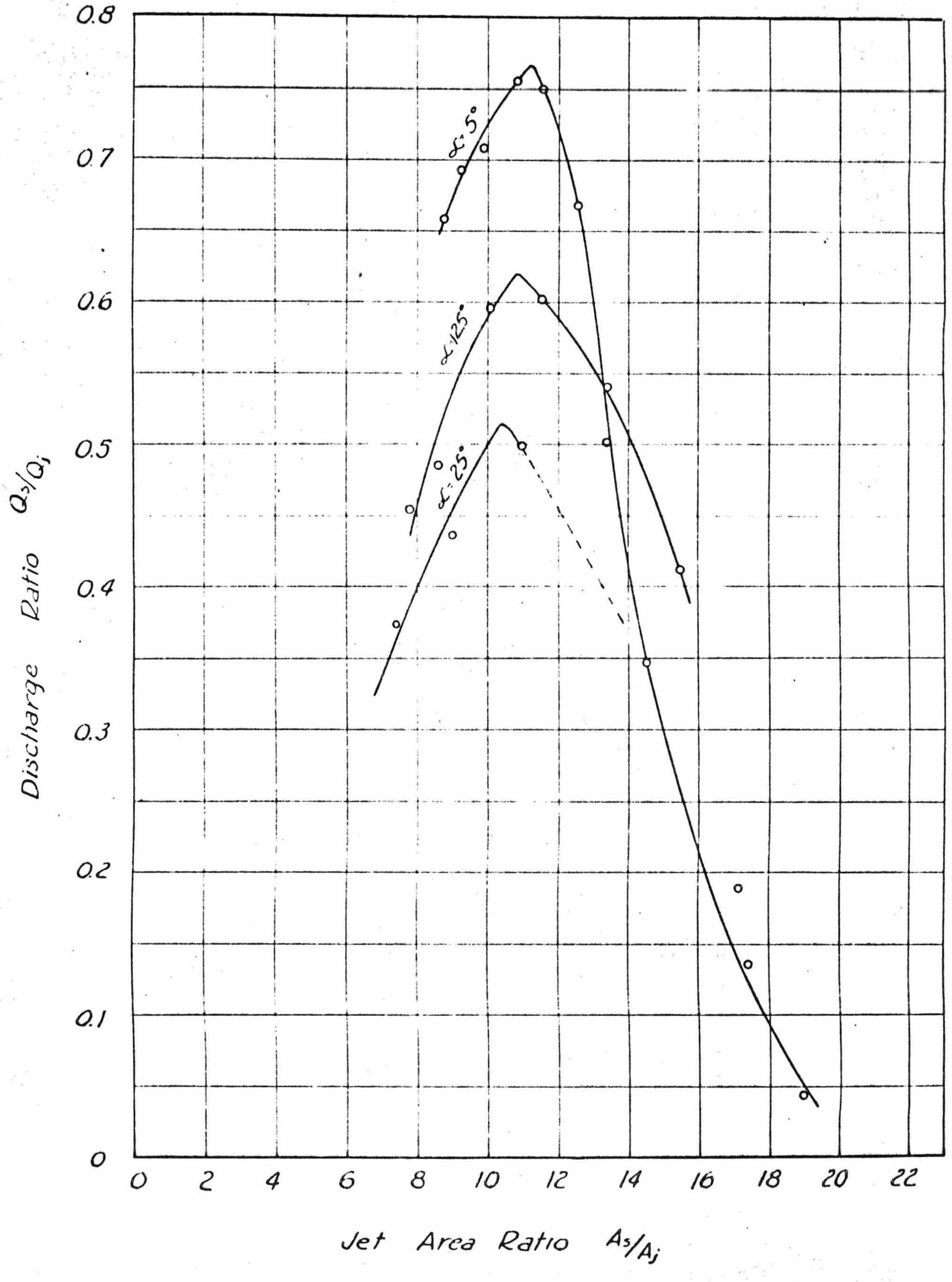
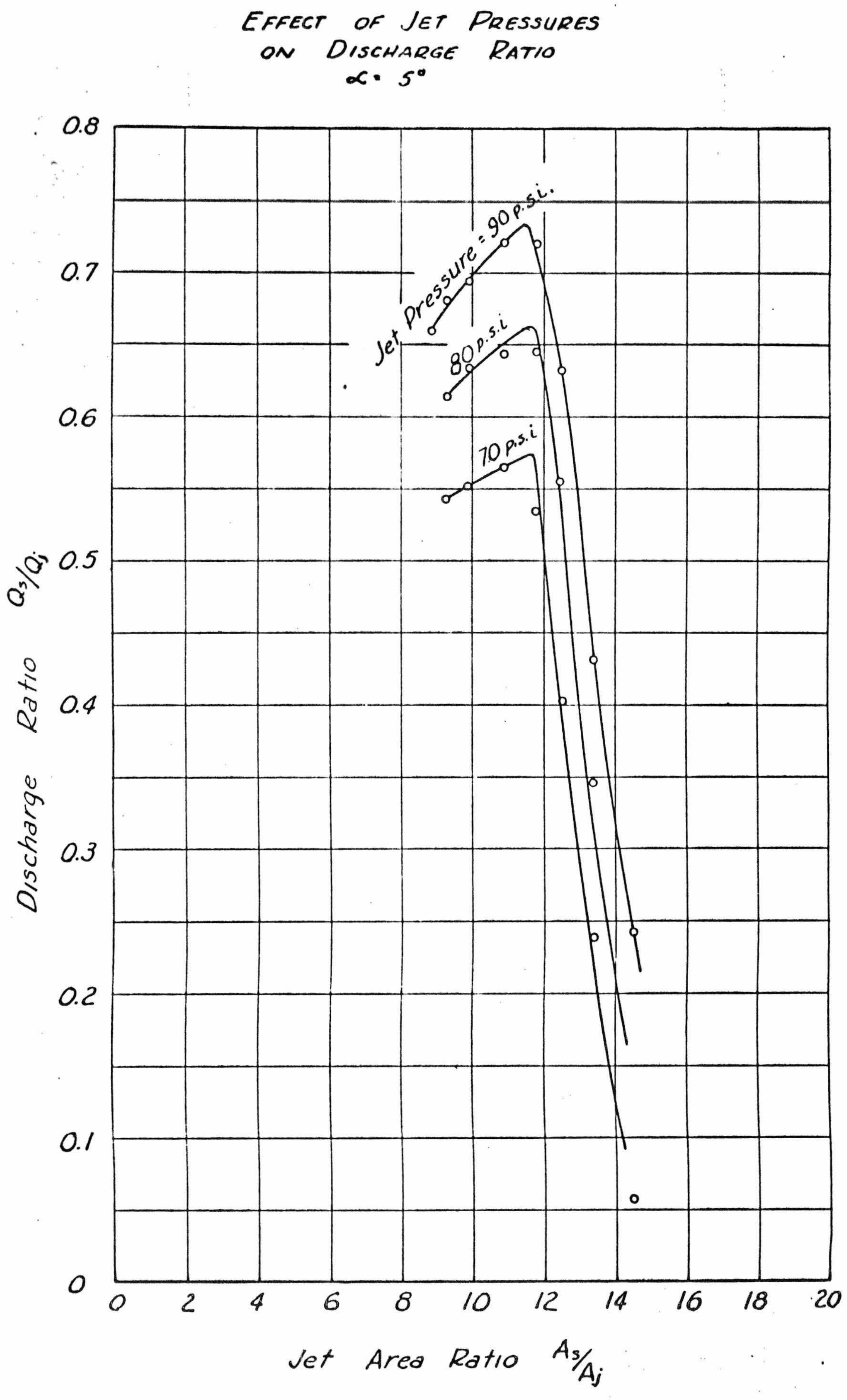
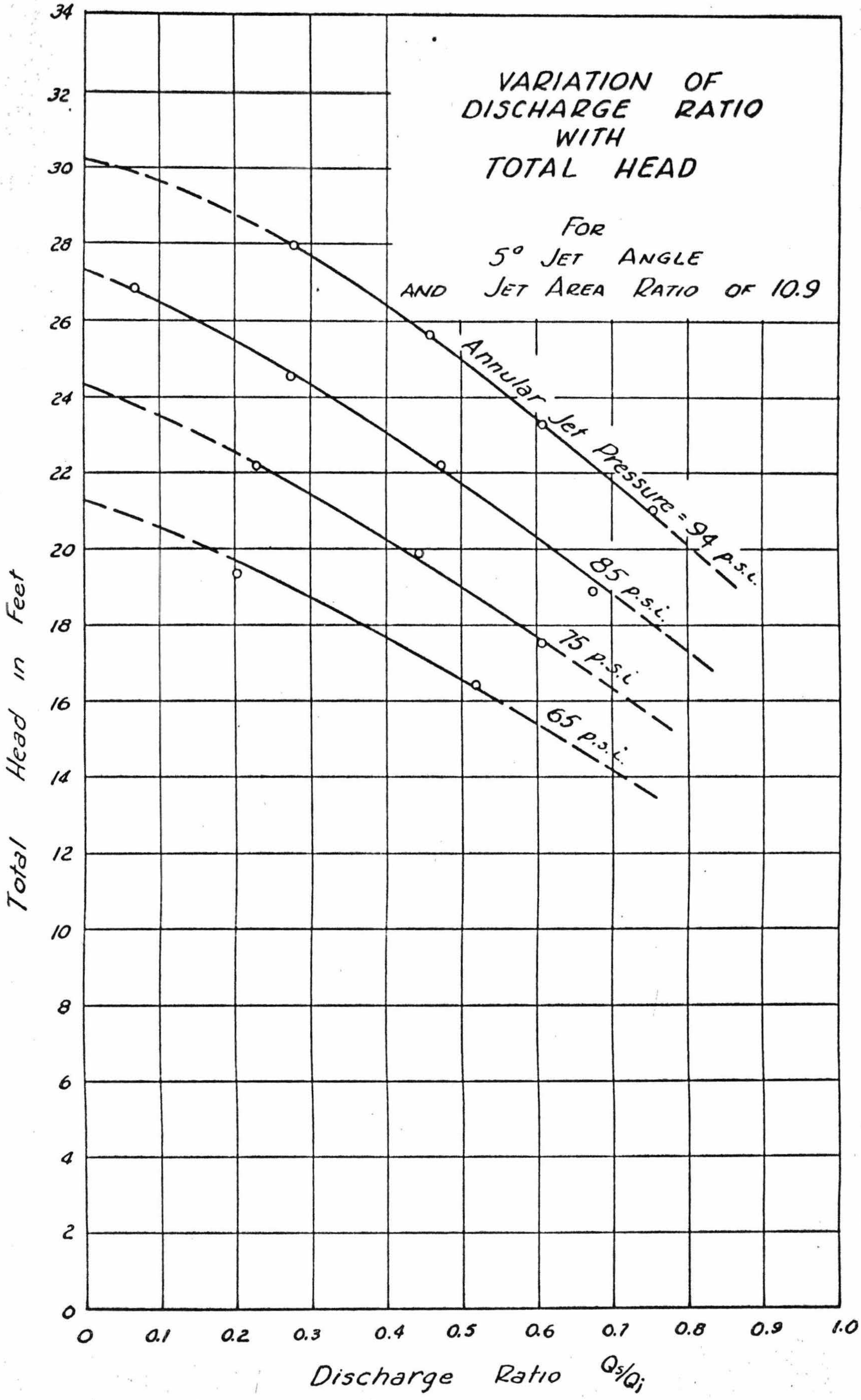


EXHIBIT 5


Effect of Jet Pressures
on Discharge Ratio
α = 5°
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Discharge Ratio Q_s/Q_j
Jet Pressure = 90 p.s.i.
80 p.s.i
70 p.s.i
0
2
4
6
8
10
12
14
16
18
20
Jet Area Ratio A_s/A_j


VARIATION OF
DISCHARGE RATIO
WITH
TOTAL HEAD
FOR
5° JET ANGLE
AND JET AREA RATIO OF 10.9
Annular Jet Pressure = 94 p.s.i.
85 p.s.i.
75 p.s.i.
65 p.s.i.
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Total Head in Feet
Discharge Ratio Qs/Qi

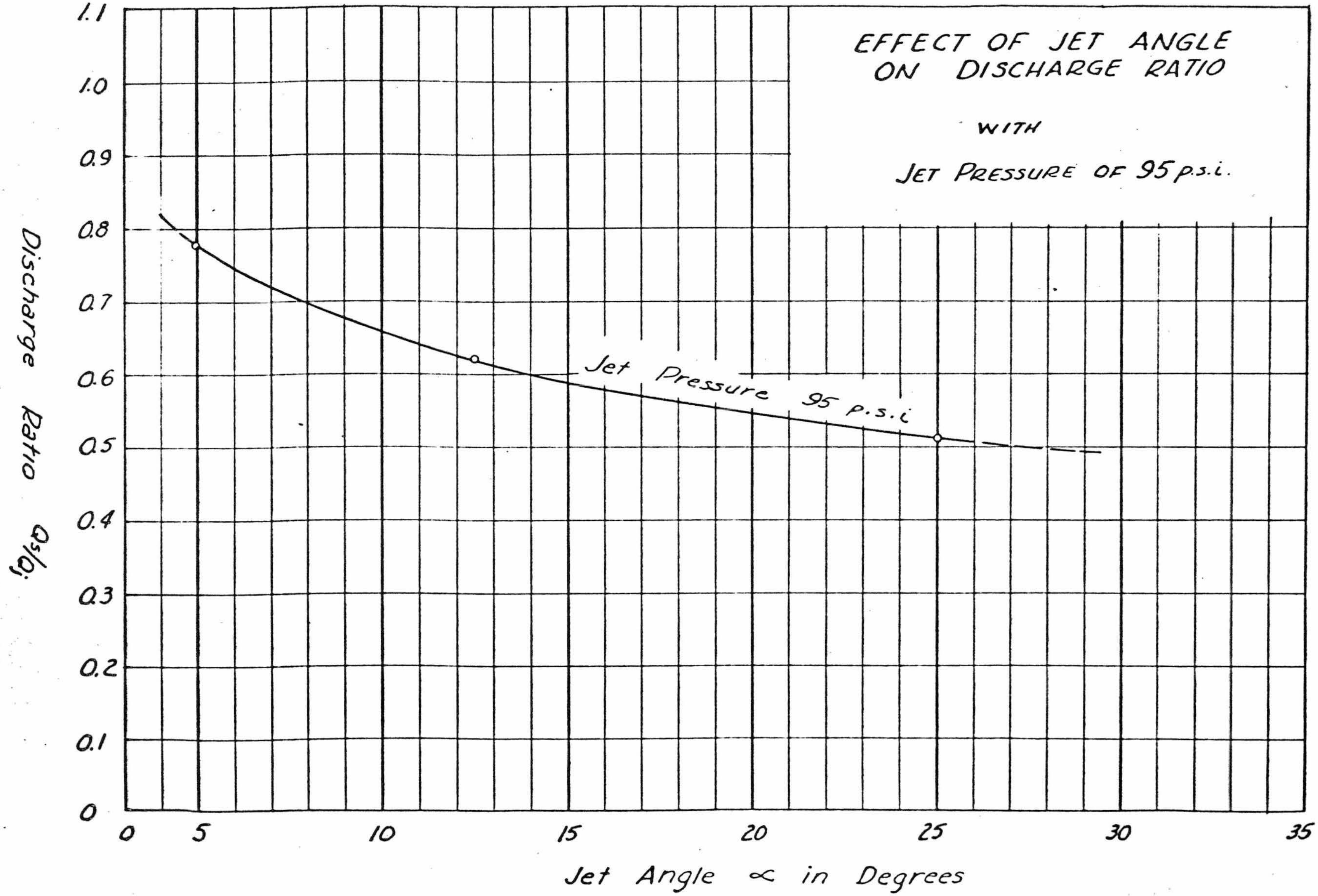
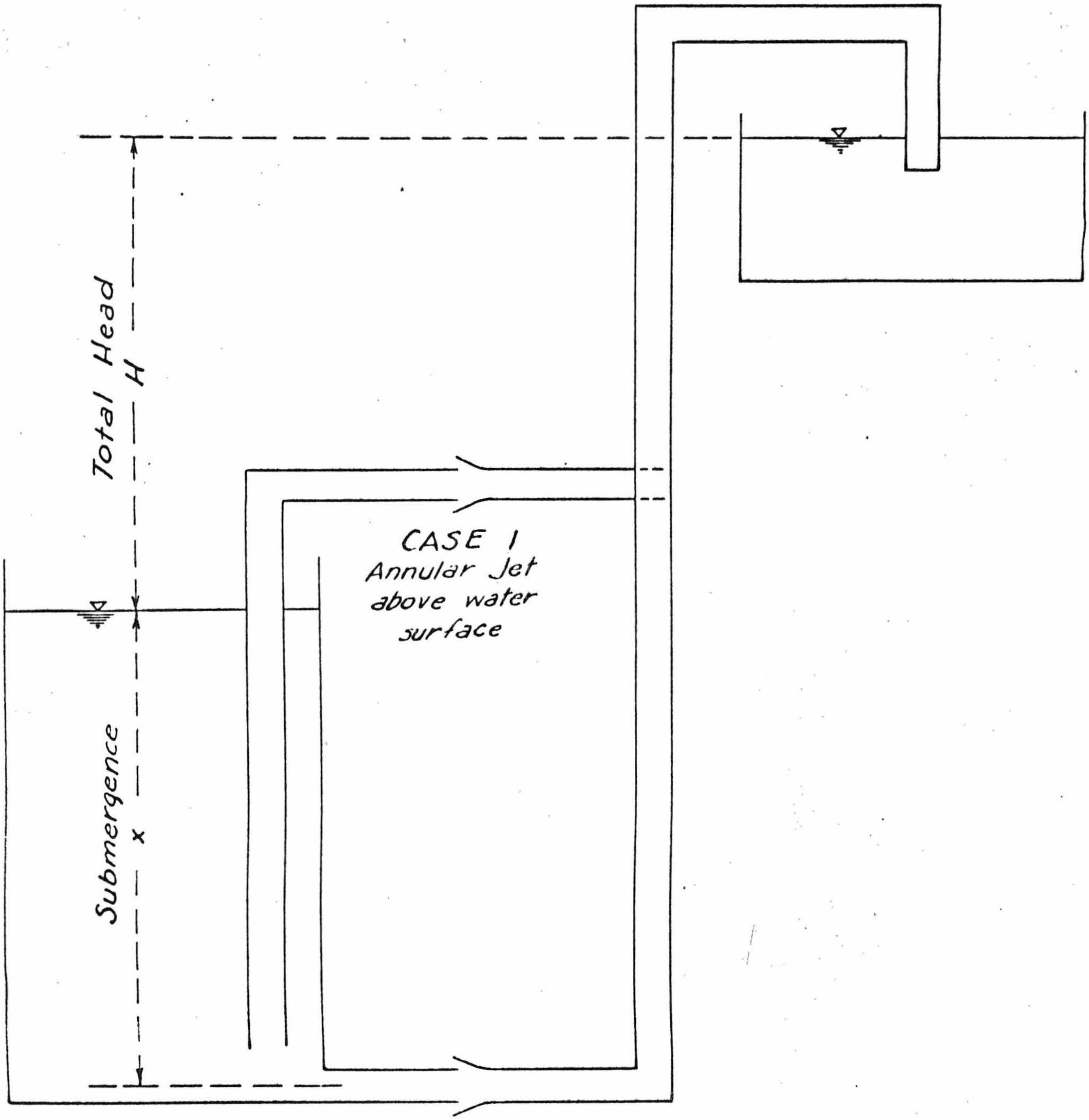

EFFECT OF JET ANGLE ON DISCHARGE RATIO
WITH
JET PRESSURE OF 95 p.s.i.
Jet Pressure 95 p.s.i
Discharge Ratio Qs/Qi
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
Jet Angle ∝ in Degrees

EXHIBIT 7

Run No.	α Jet Angle	A_j Jet Area	P_j Jet Pressure	Q_j Jet Discharge	Q_t Total Discharge	W_g Gravel Transport	H_t Total Head	Q_s Induced Discharge	Q_s/Q_j Discharge Ratio	C Concen-tration	Remarks
Units	Degrees	Ft^2	p.s.i.	g.p.m.	g.p.m.	t.p.h.	Ft.	g.p.m.		%	
4	5	.0075	95	306	400	10.3	17	94	.307	9.3	Gravel
8	5	.0088	94	322	435	11.4	17	113	.260	9.5	Gravel
11	5	.0088	92	366	490	15.1	22	123	.336	11.0	Gravel
12	5	.0094	90	390	515	15.2	23	125	.243	10.6	Gravel
13	5	.0088	92	364	470	19.3	22	106	.291	14.1	Sand & Gravel
14	5	.0088	92	364	460	18.4	22	96	.264	13.8	Sand & Gravel

Concentration is expressed in terms of total discharge by weight.



CASE 2

Annular Jet below water surface

EXPLANATION DIAGRAM
FOR POSITION OF ANNULAR JET