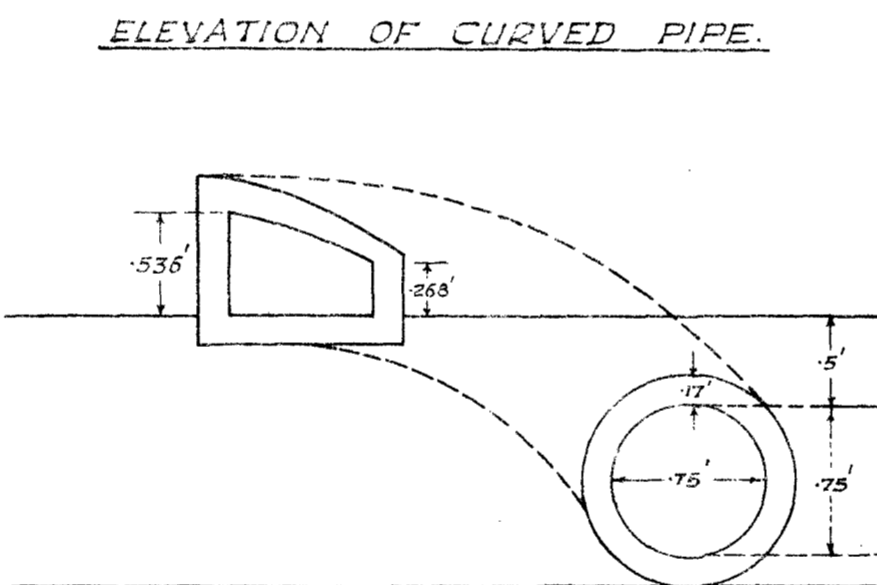
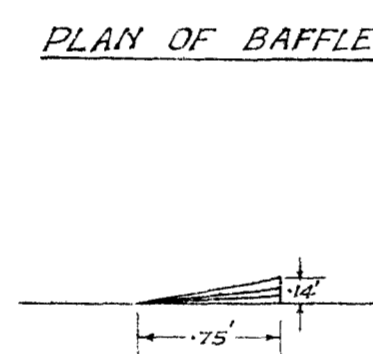
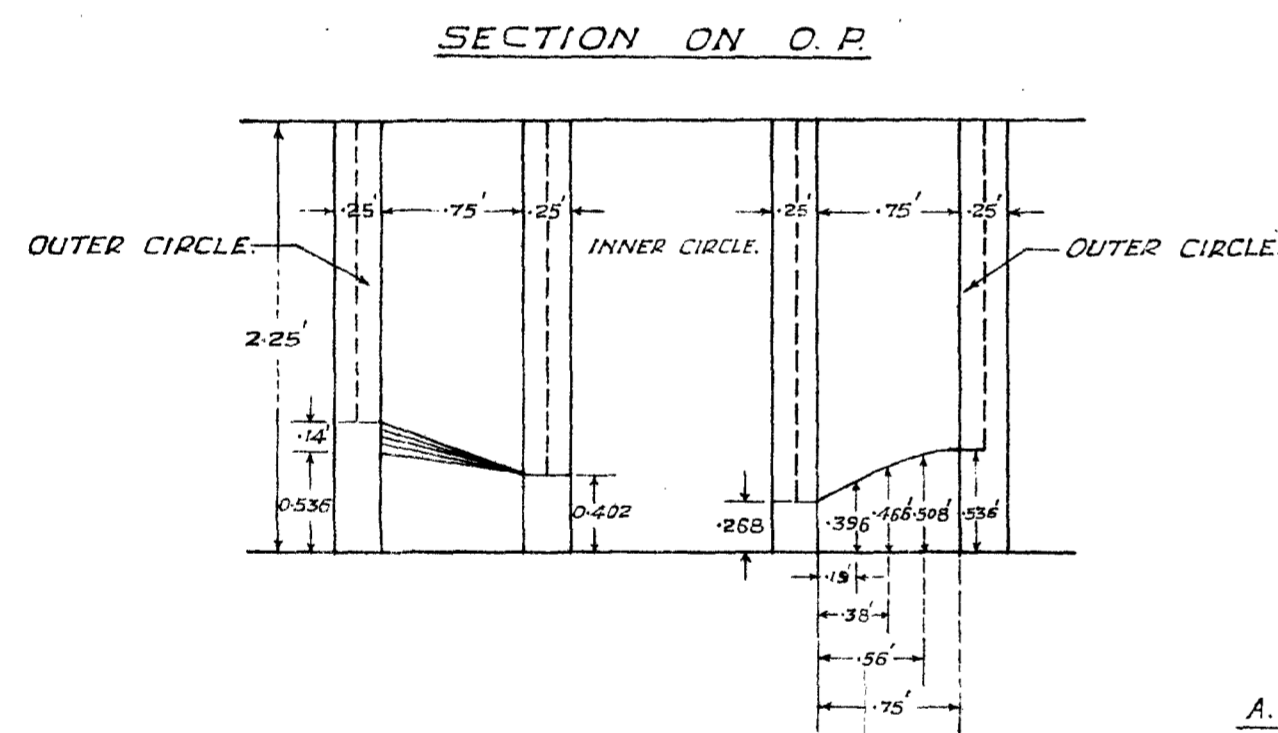
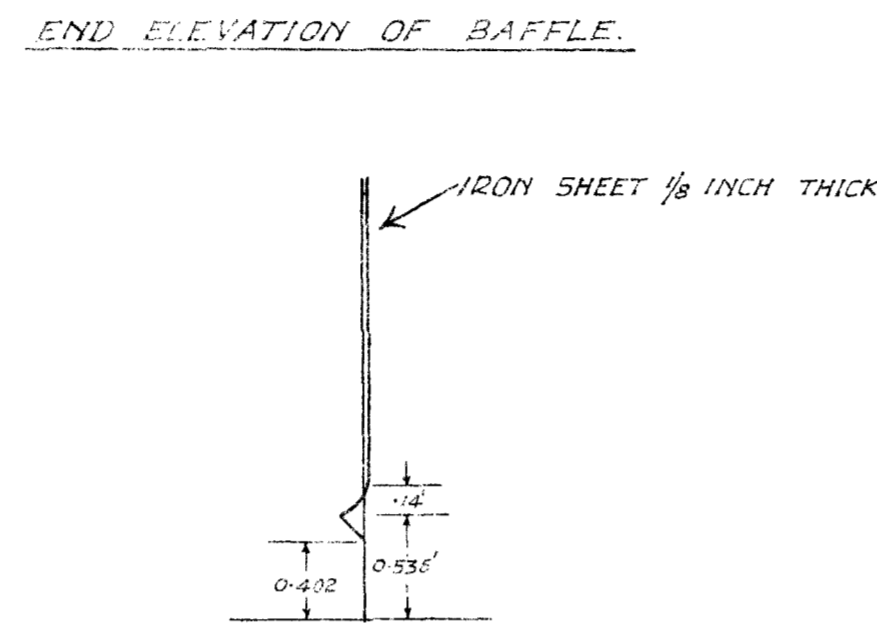
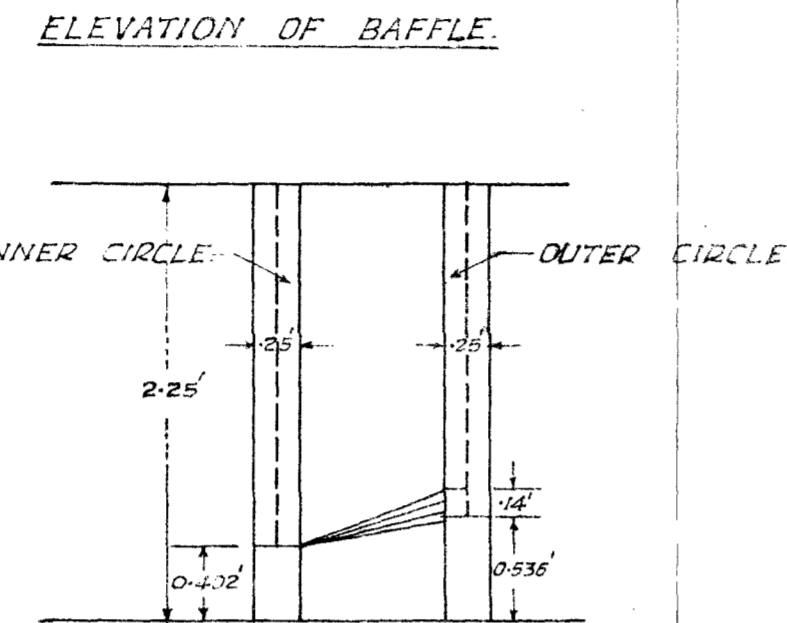
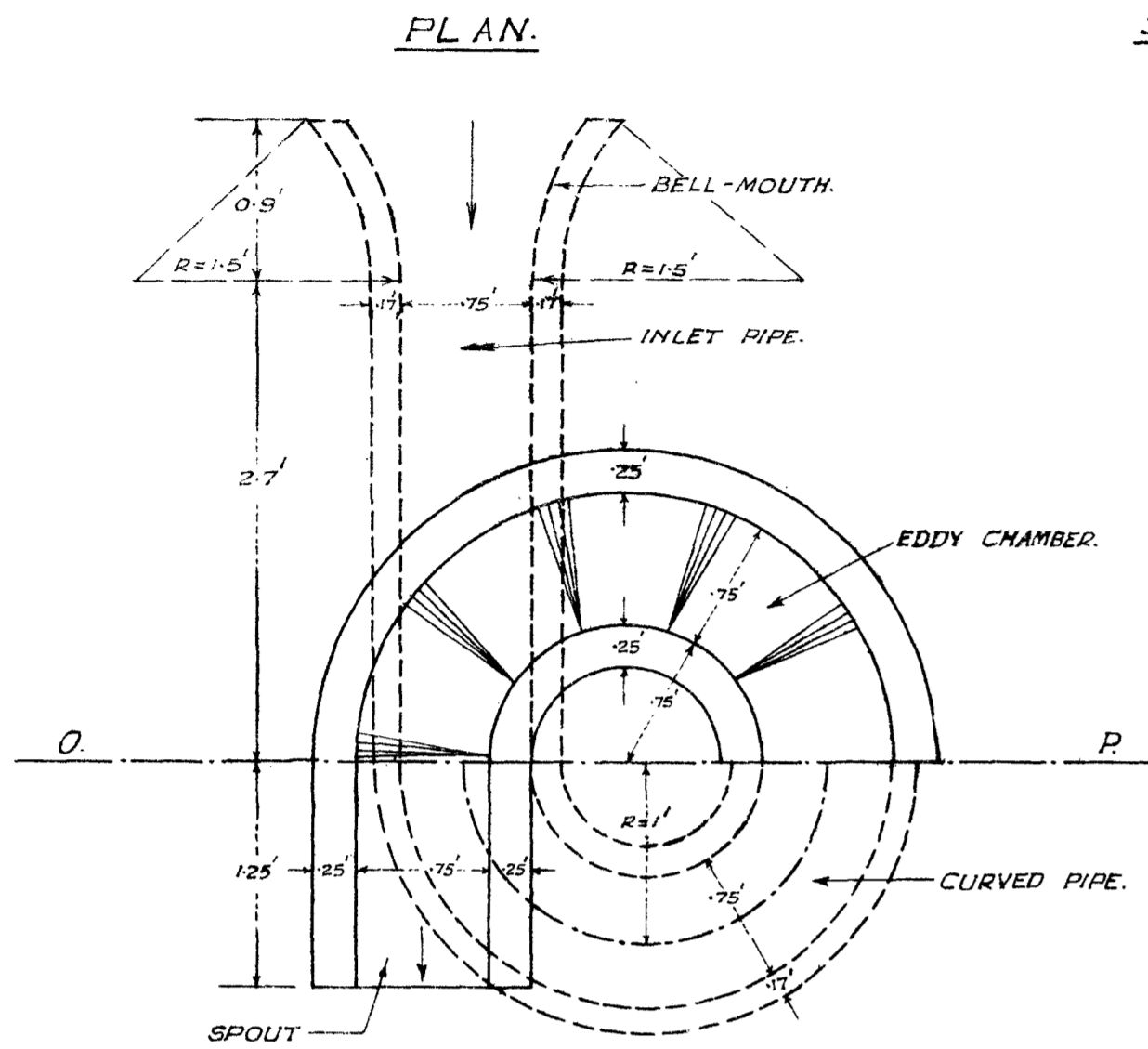
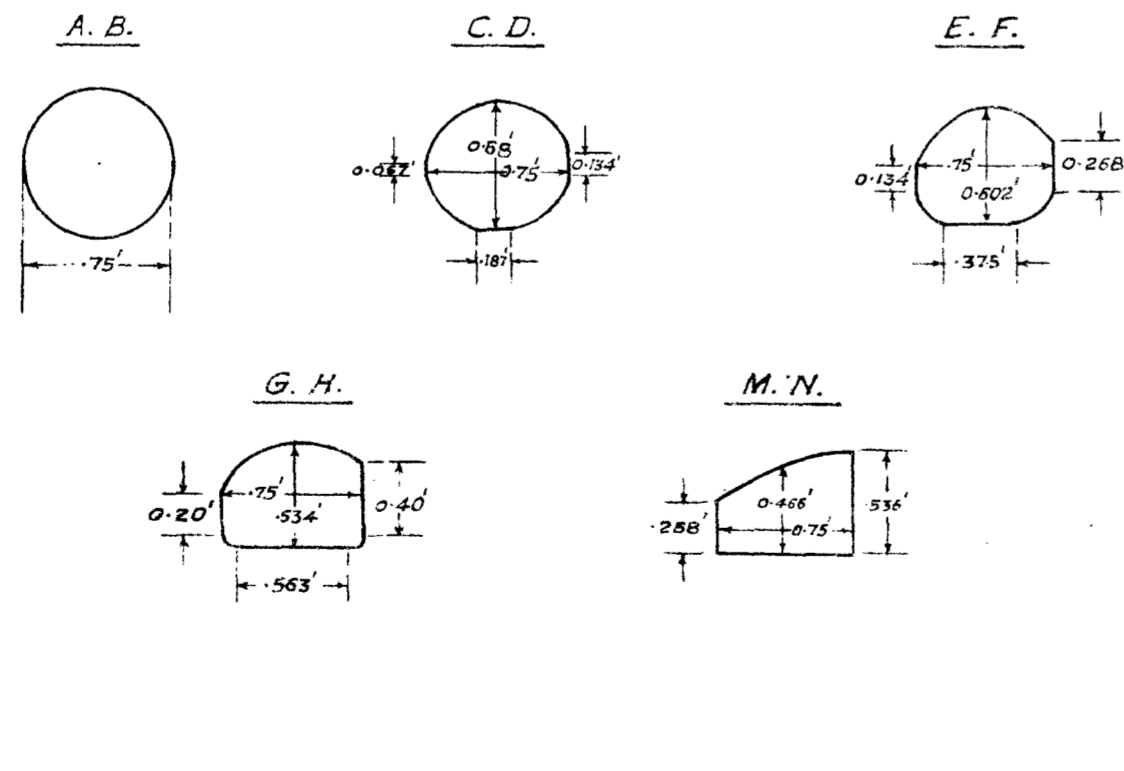


1 CUSEC GIBB MODULE.
SCALE:- 1 INCH = 1 FOOT.



SECTIONS IN CURVED PIPE ON



CURVED PIPE.

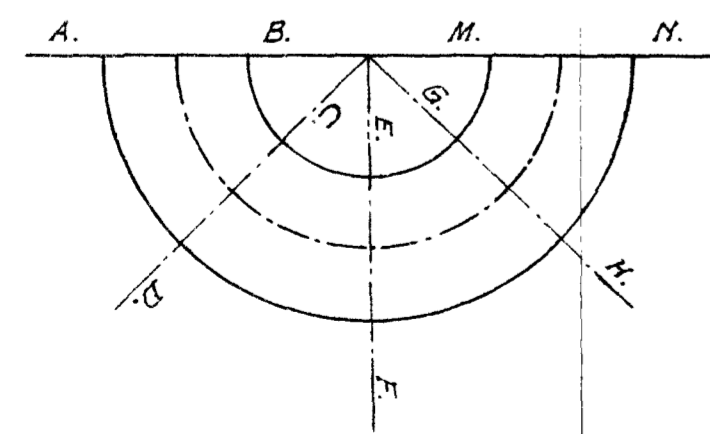


TABLE SHOWING DIMENSIONS OF 1, 2 & 3 CUSECS R.C.C. GIBB MODULES.
(ALL DIMENSIONS ARE IN FEET.)

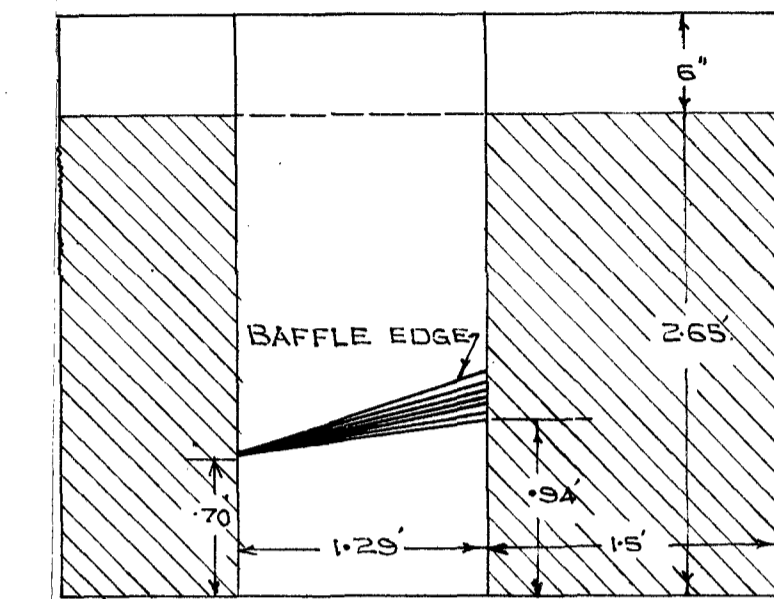
	1 CUSEC MODULE.	2 CUSECS MODULE.	3 CUSECS MODULE.
BELL-MOUTH.			
(1) LENGTH OF BELL-MOUTH.	0.9	1.0	1.2
(2) RADIUS OF BELL-MOUTH.	1.5	1.66	2.0
INLET PIPE.			
(3) DIAMETER OF INLET PIPE.	0.75	0.83	1.0
(4) LENGTH OF INLET PIPE.	2.7	3.0	3.6
CURVED PIPE.			
(5) RADIUS OF CENTRE LINE OF CURVED PIPE.	1.0	1.0	1.5
(6) DISTANCE BETWEEN TOP OF CURVED PIPE & FLOOR OF MODULE.	0.5	0.5	0.5
EDDY CHAMBER.			
(7) r_o = RADIUS OF OUTER SEMI-CIRCLE.	1.5	1.916	2.75
(8) r_i = RADIUS OF INNER SEMI-CIRCLE.	0.75	0.958	1.375
(9) B = WIDTH OF EDDY CHAMBER.	0.75	0.958	1.375
(10) HEIGHT OF EDDY CHAMBER.	2.25	2.56	2.6
(11) LENGTH OF SPOUT.	1.25	1.68	1.75
BAFFLES.			
(12) NUMBER OF BAFFLES.	5	5	6
(13) HEIGHT OF LOWER EDGE OF BAFFLES FROM MODULE FLOOR AT OUTER CIRCLE	0.536	0.72	0.75
AT INNER CIRCLE	0.402	0.54	0.562
(14) RADIUS OF LOWER EDGE OF BAFFLES AT OUTER CIRCLE.	0.14	0.18	0.22
(15) CROSS SECTIONS AT JUNCTION OF CURVED PIPE & EDDY CHAMBER.			
d_o = DEPTH OF WATER AT OUTER CIRCUMFERENCE.	0.536 AT 0.75 FROM INNER CIRCLE.	0.72 AT 0.958 FROM INNER CIRCLE.	0.75 AT 1.375 FROM INNER CIRCLE.
d_i = DEPTH OF WATER AT INNER CIRCUMFERENCE.	0.508 AT 0.56 FROM INNER CIRCLE. 0.466 AT 0.38 FROM INNER CIRCLE. 0.396 AT 0.19 FROM INNER CIRCLE. 0.268 AT INNER CIRCLE.	0.69 AT 0.718 FROM INNER CIRCLE. 0.63 AT 0.479 FROM INNER CIRCLE. 0.54 AT 0.239 FROM INNER CIRCLE. 0.36 AT INNER CIRCLE	0.72 AT 1.031 FROM INNER CIRCLE. 0.653 AT 0.687 FROM INNER CIRCLE. 0.555 AT 0.344 FROM INNER CIRCLE. 0.375 AT INNER CIRCLE
(16) DEVELOPMENT OF CURVED PIPE.			
CROSS SECTION A. B.	0.75	0.83	1.0
CROSS SECTION C. D.	0.067, 0.187, 0.134, 0.75, 0.68.	0.09, 0.24, 0.18, 0.86, 0.78.	0.094, 0.34, 0.10, 1.09, 0.914.
CROSS SECTION E. F.	0.134, 0.375, 0.268, 0.75, 0.602.	0.18, 0.48, 0.36, 0.89, 0.73.	0.187, 0.68, 0.374, 1.18, 0.826.
CROSS SECTION G. H.	0.20, 0.563, 0.40, 0.75, 0.534.	0.27, 0.71, 0.54, 0.92, 0.68.	0.282, 1.02, 0.564, 1.27, 0.74.
CROSS SECTION M. N.	SEE ITEM (15)	SEE ITEM (15)	SEE ITEM (15)

4 CUSECS GIBB MODULE.

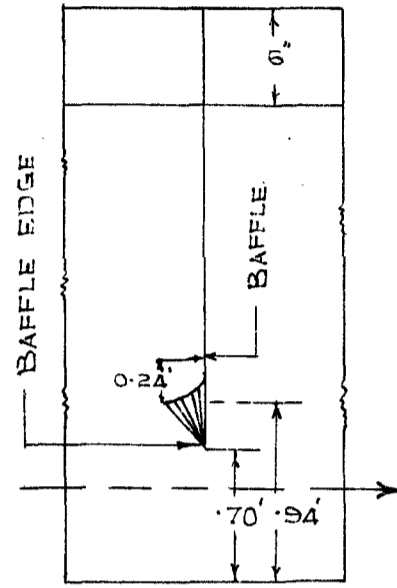
SCALE: 3 FEET = 1"

ENLARGED VIEW OF BAFFLE

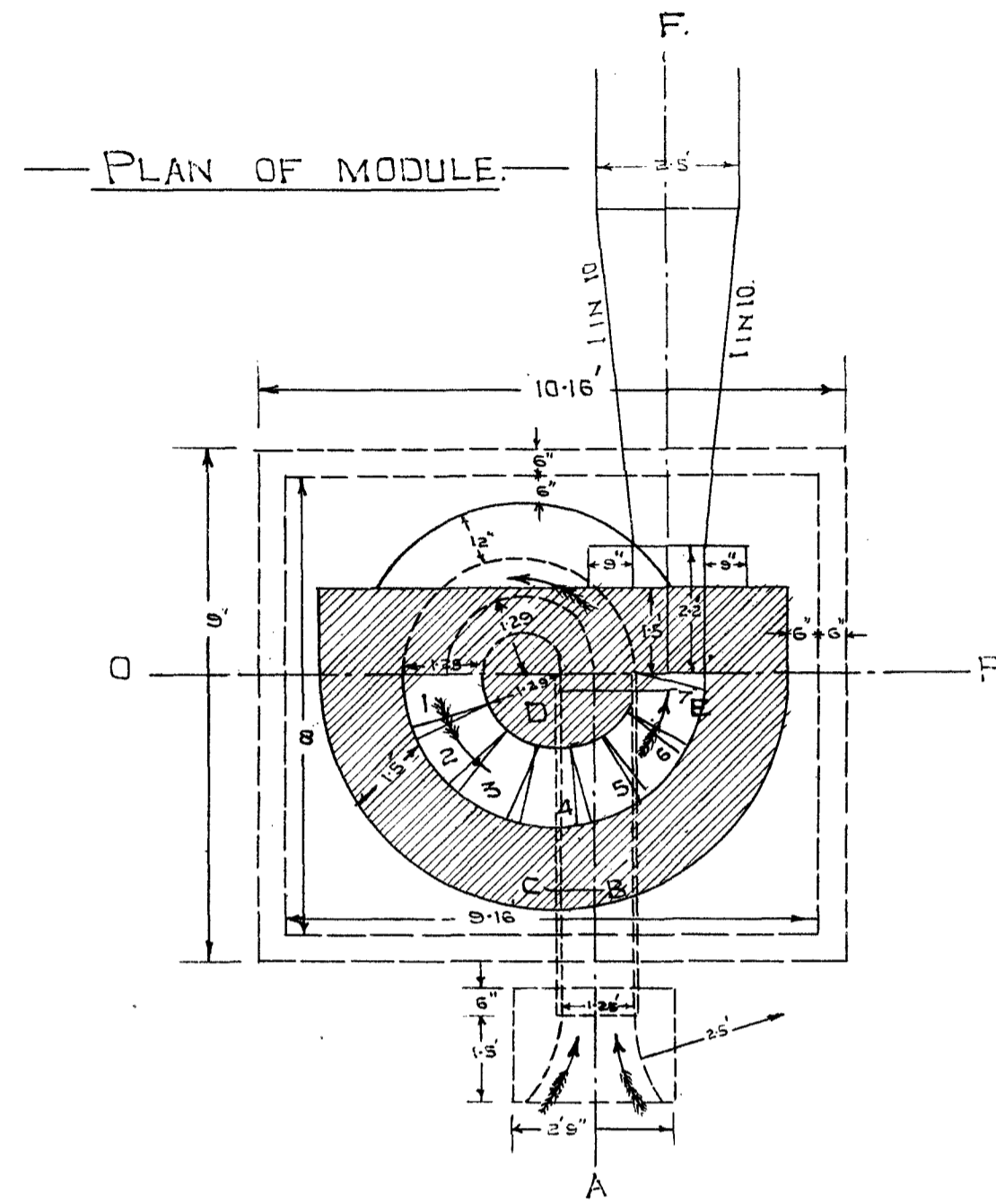
SCALE: 1" = 1 INCH.



FRONT VIEW

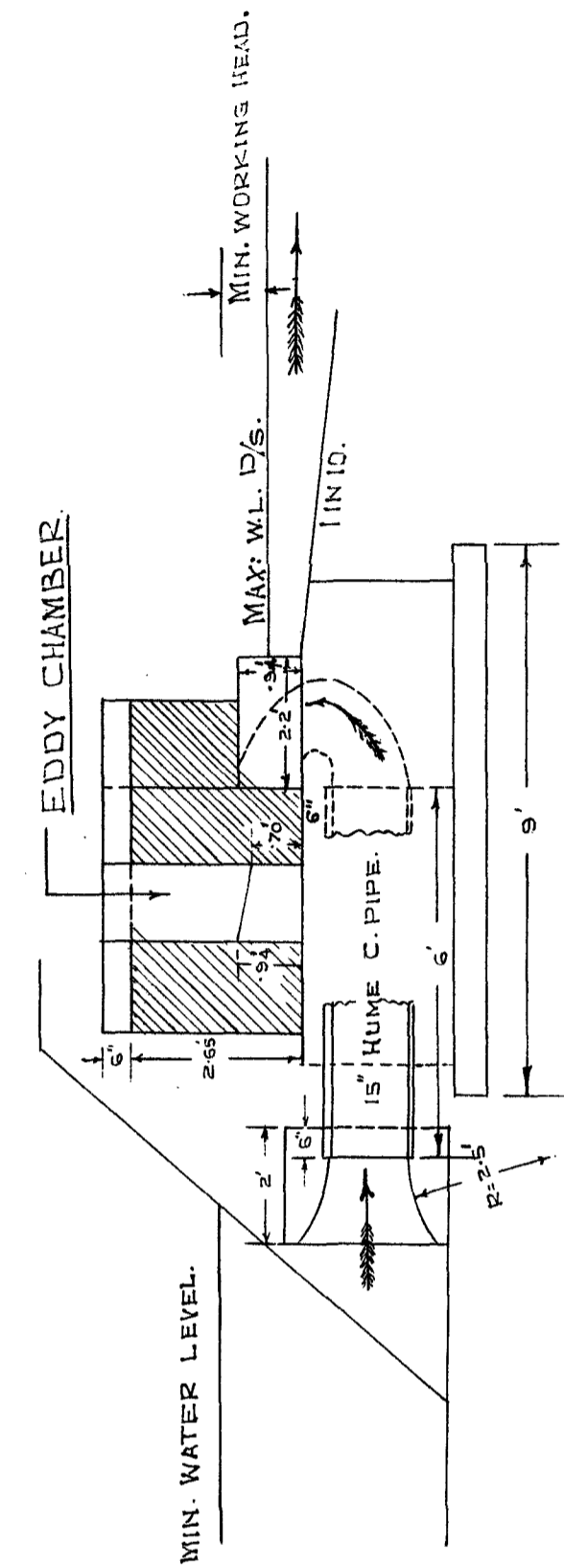


SIDE VIEW

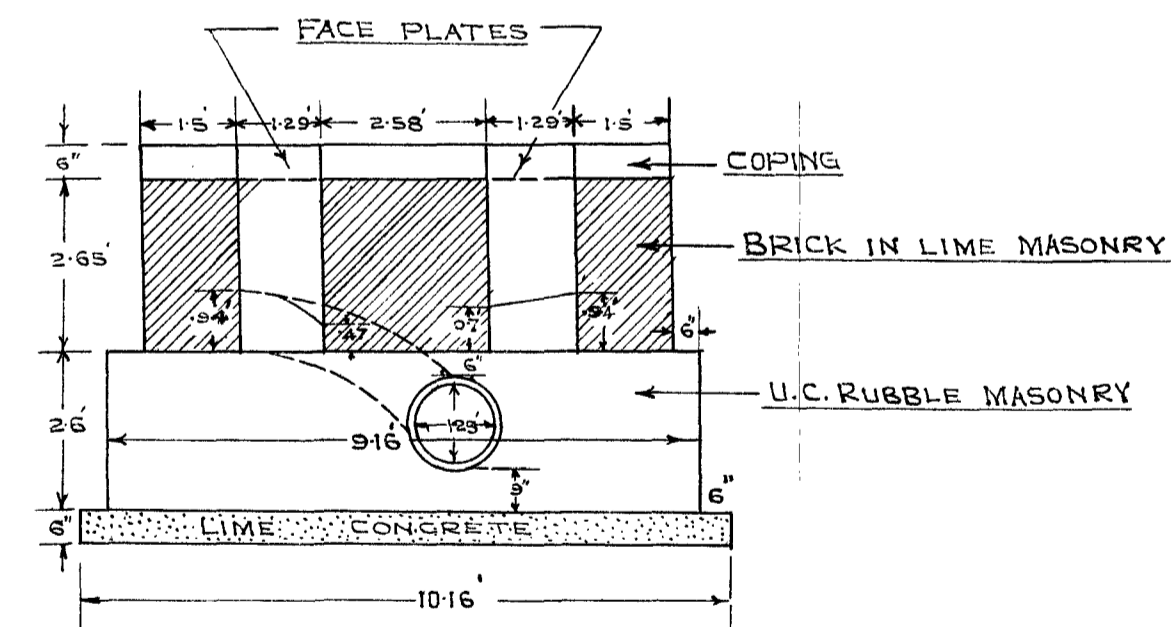


PLAN OF MODULE

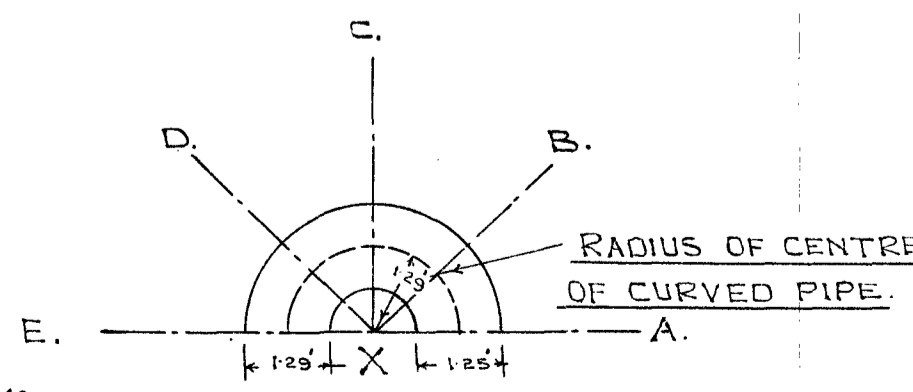
SECTION ALONG A.B.C.D.E.F.



SECTION ALONG O.P.



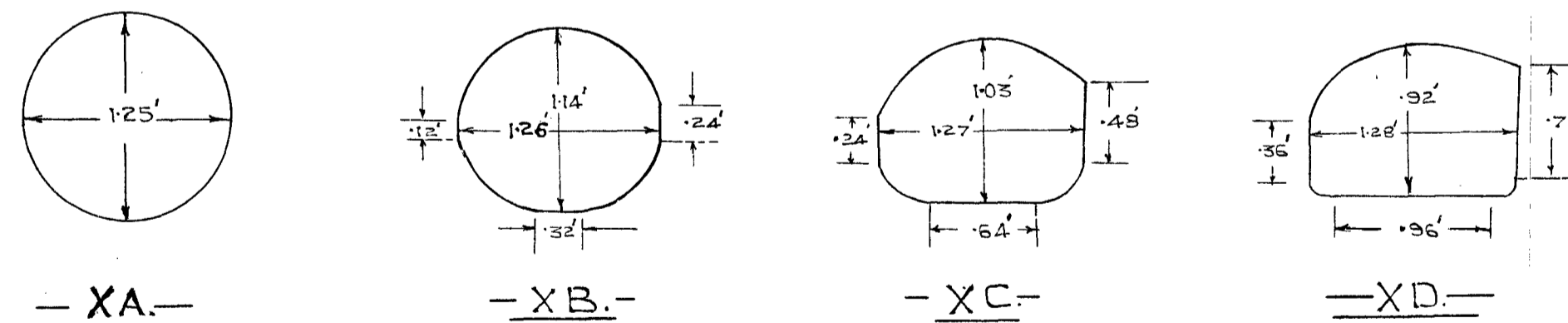
PLAN OF CURVED PIPE



RADIUS OF CENTRE OF CURVED PIPE.

ENLARGED SECTIONS OF CURVED PIPE

SCALE: 1" = 1 INCH.

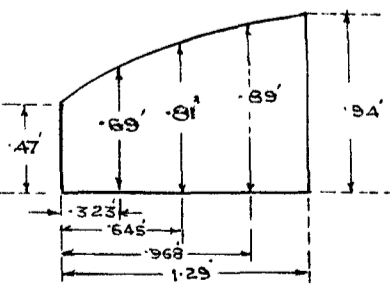


XA

XB

XC

XD



XE

TABLE SHOWING DIMENSIONS OF 4, 5, 8, 10 & 16 CUSECS GIBB MODULES.

(IN BRICK MASONRY WITH CEMENT PLASTER ON THE INSIDE & CEMENT POINTING ON THE OUTSIDE.)

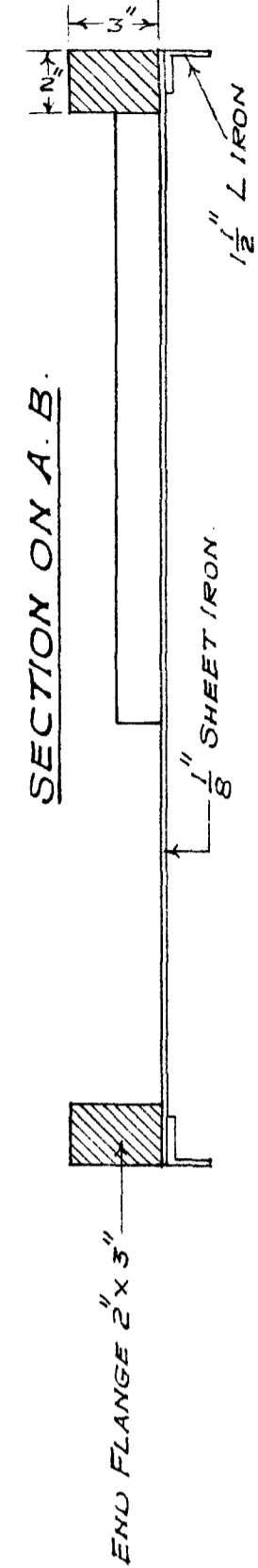
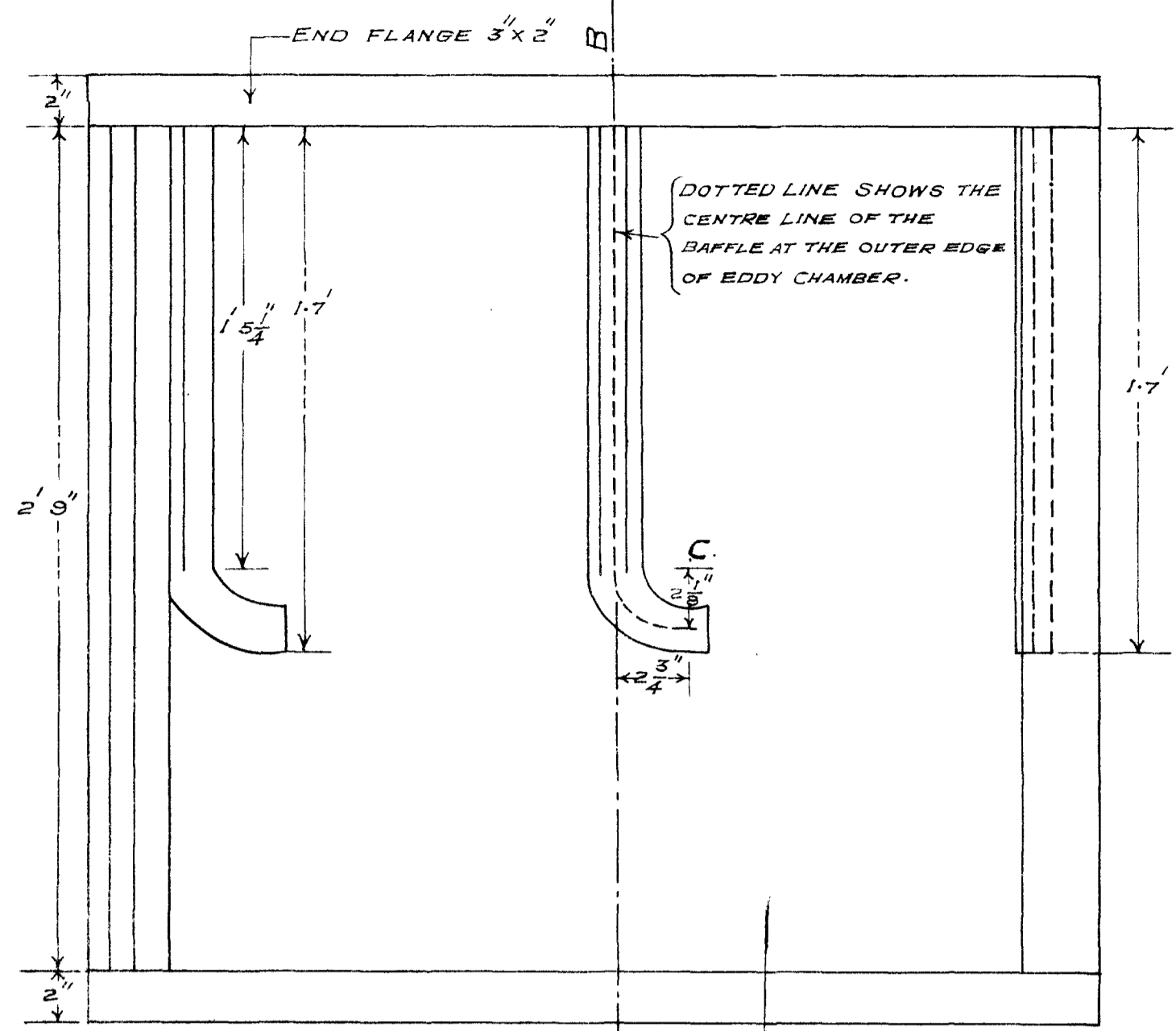
ALL DIMENSIONS ARE IN FEET.

	4 CUSECS MODULE	5 CUSECS MODULE	8 CUSECS MODULE	10 CUSECS MODULE	16 CUSECS MODULE
BELL MOUTH					
1	1.5	1.5	1.8	2.1	2.4
2	2.5	2.5	3.0	3.5	4.0
INLET PIPE					
3	1.25	1.25	1.5	1.75	2.0
4	6.0	6.0	6.0	8.0	8.0
CURVED PIPE					
5	1.29	1.375	1.625	1.832	2.5
6	0.5	0.5	0.5	0.5	0.5
EDDY CHAMBER					
7	2.58	2.75	3.25	3.64	5.0
8	1.29	1.375	1.625	1.832	2.5
9	1.29	1.375	1.625	1.832	2.5
10	3.15	3.58	4.25	4.3	5.0
11	2.2	2.44	3.15	3.15	3.5
BAFFLES					
12	7	7	7	8	10
13	0.94	1.04	1.34	1.366	1.519
14	0.70	0.78	1.0	1.025	1.14
15	0.24	0.26	0.33	0.34	0.38
CROSS SECTION AT JUNCTION OF CURVED PIPE & EDDY CHAMBER					
d_0 = DEPTH OF WATER AT OUTER CIRCUMFERENCE	0.94 AT 1.29 FROM INNER CIRCLE	1.04 AT 1.375 FROM INNER CIRCLE.	1.34 AT 1.625 FROM INNER CIRCLE	1.366 AT 1.832 FROM INNER CIRCLE	1.519 AT 2.5 FROM INNER CIRCLE.
	0.89 AT 0.968 FROM INNER CIRCLE.	0.905 AT 1.032 " " "	1.27 AT 1.22 " " "	1.298 AT 1.374 " " "	1.442 AT 1.875 " " "
	0.81 AT 0.645 FROM INNER CIRCLE.	0.77 AT 0.544 " " "	1.0 AT 0.407 " " "	1.014 AT 0.458 " " "	1.322 AT 1.25 " " "
	0.69 AT 0.323 FROM INNER CIRCLE.	0.52 AT INNER CIRCLE	0.67 AT INNER CIRCLE.	0.69 AT INNER CIRCLE.	1.32 AT 0.625 " " "
d_i = DEPTH OF WATER AT INNER CIRCUMFERENCE.	0.47 AT INNER CIRCLE.				0.76 AT INNER CIRCLE.
DEVELOPMENT OF CURVED PIPE					
C.S. XA.	1.25	1.25	1.5	1.75	2.0
XB.	0.12; 0.52; 0.24; 1.26; 1.14.	0.13; 0.54; 0.26; 1.25; 1.17.	0.17; 0.40; 0.34; 1.53; 1.42.	0.17; 0.46; 0.34; 1.77; 1.61.	0.19; 0.61; 0.38; 2.125; 1.87.
XC.	0.24; 0.64; 0.48; 1.27; 1.03	0.26; 0.69; 0.52; 1.312; 1.09.	0.34; 0.80; 0.67; 1.56; 1.34.	0.34; 0.92; 0.68; 1.79; 1.47.	0.38; 1.25; 0.76; 2.25; 1.66.
XD.	0.36; 0.96; 0.71; 1.28; 0.92	0.39; 1.03; 0.75; 1.343; 1.08.	0.51; 0.80; 1.0; 1.59; 1.26.	0.51; 1.38; 1.02; 1.8; 1.33.	0.57; 1.87; 1.14; 2.375; 1.49.
XE.	SEE ITEM (15)	SEE ITEM (15).	SEE ITEM (15).	SEE ITEM (15)	SEE ITEM (15)

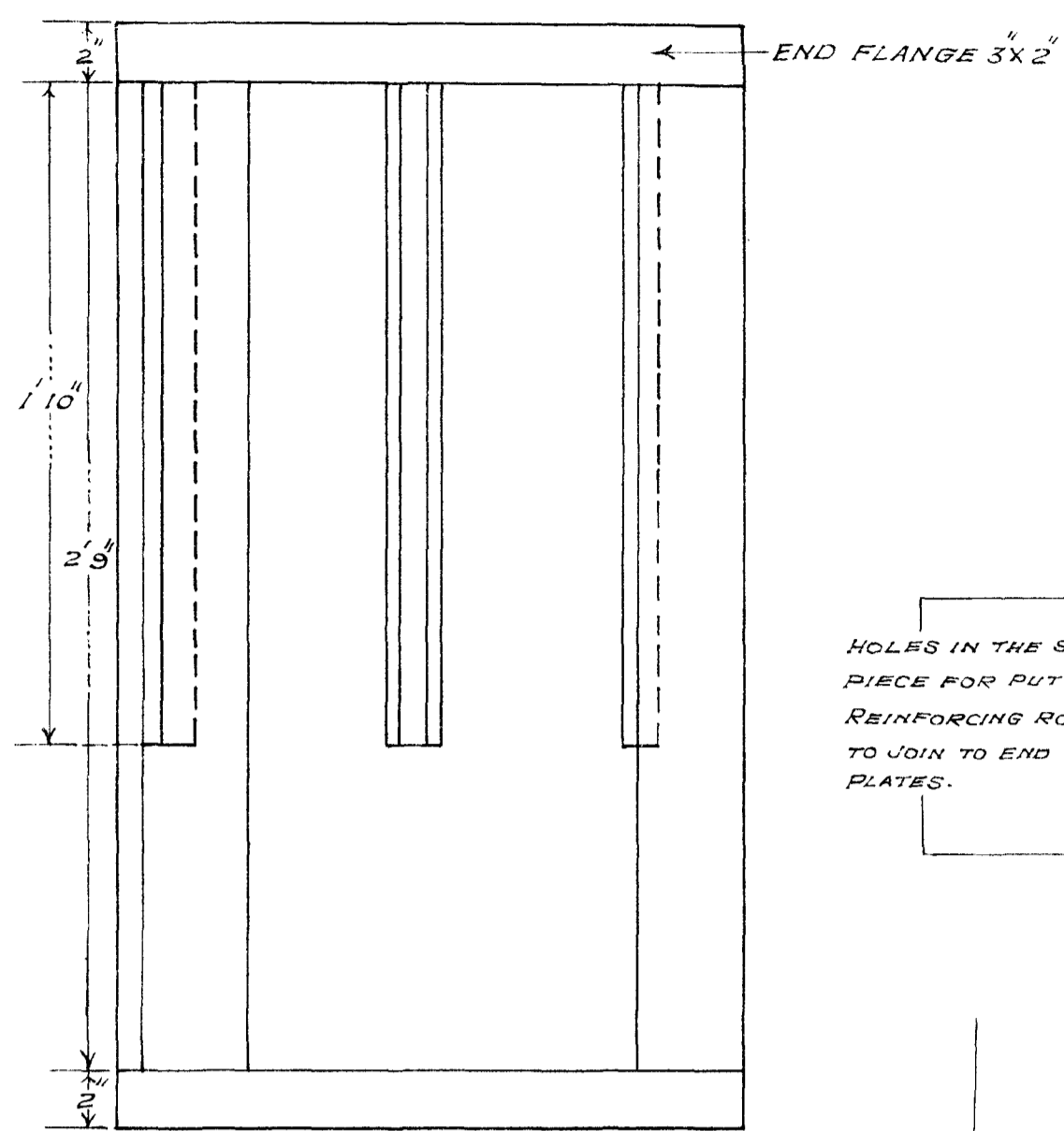
MIDDLE PORTION OF THE EDDY CHAMBER.

LEFT HAND PORTION OF THE EDDY CHAMBER.

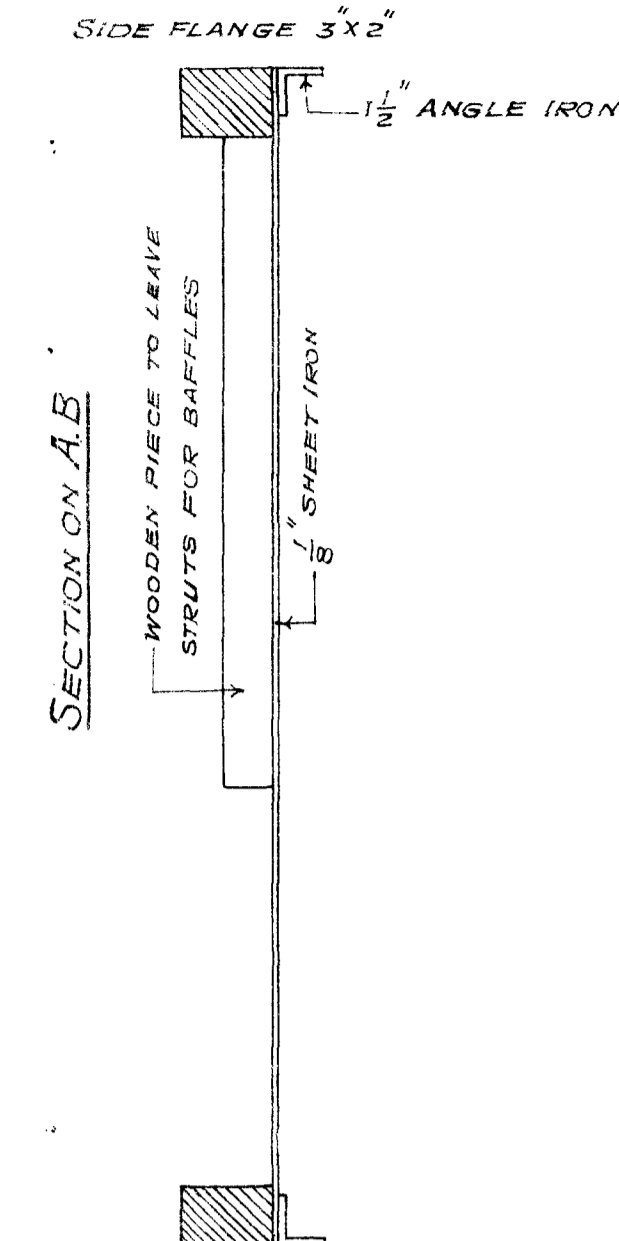
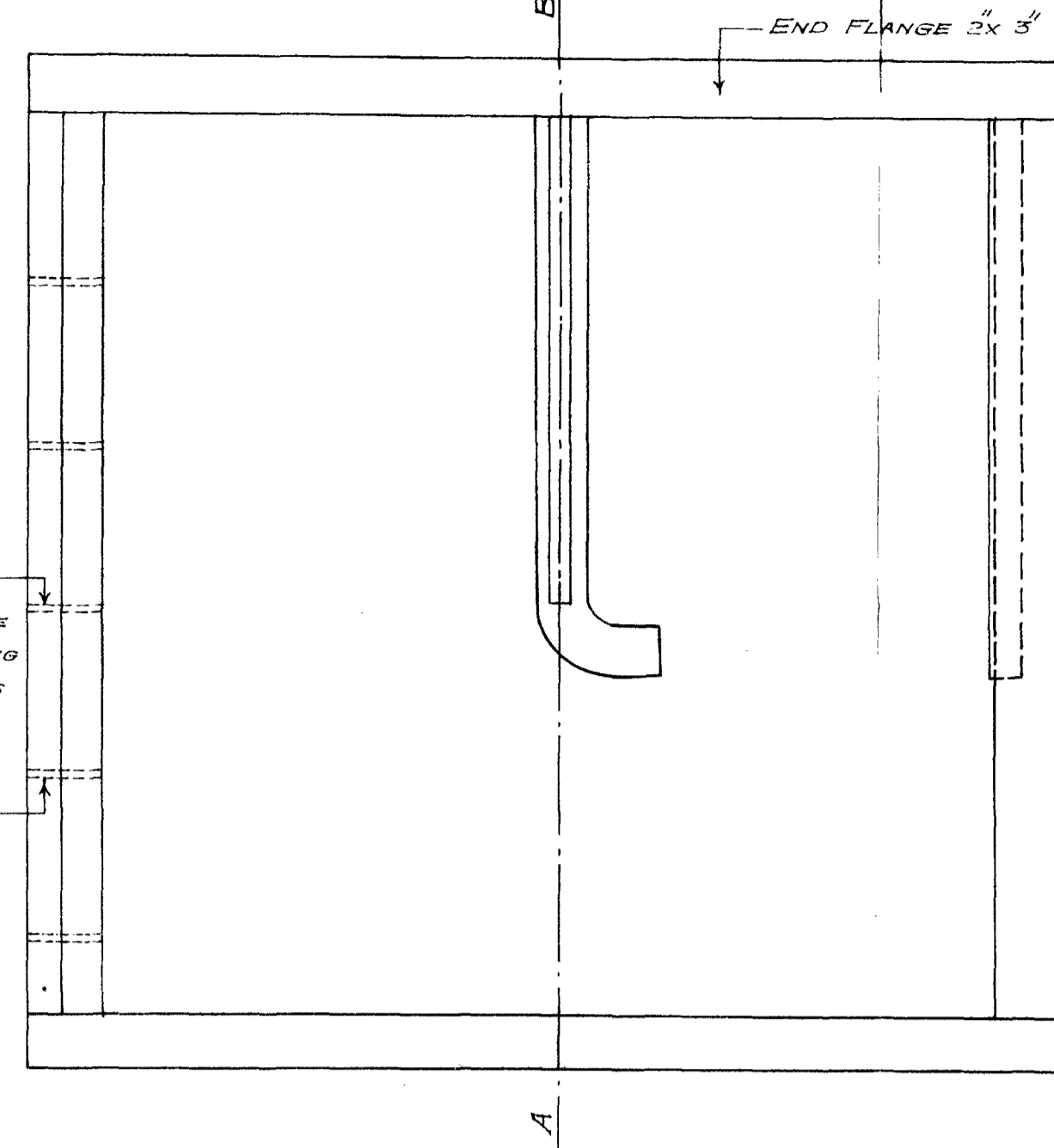
OUTER SIDE PLAN
FIG. I



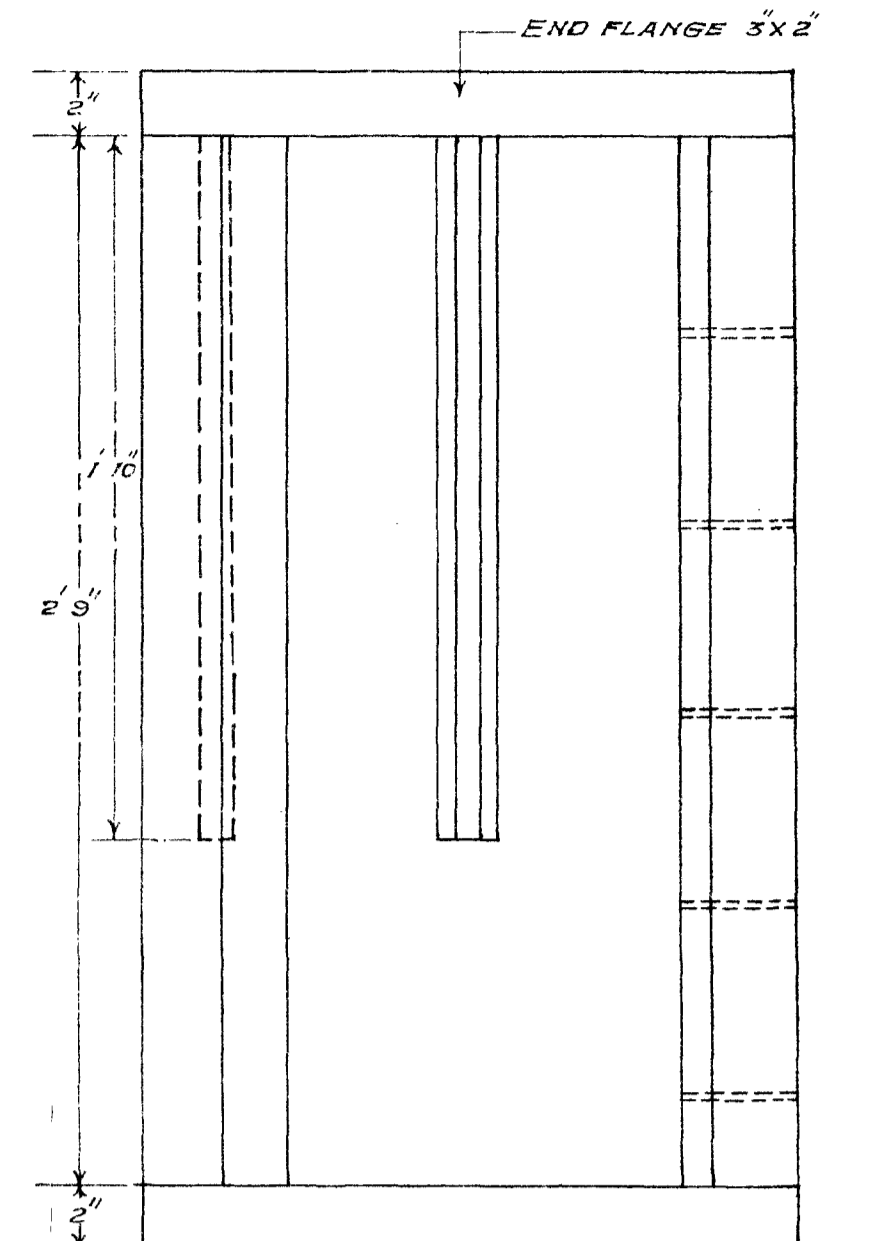
INNER SIDE PLAN
FIG. III



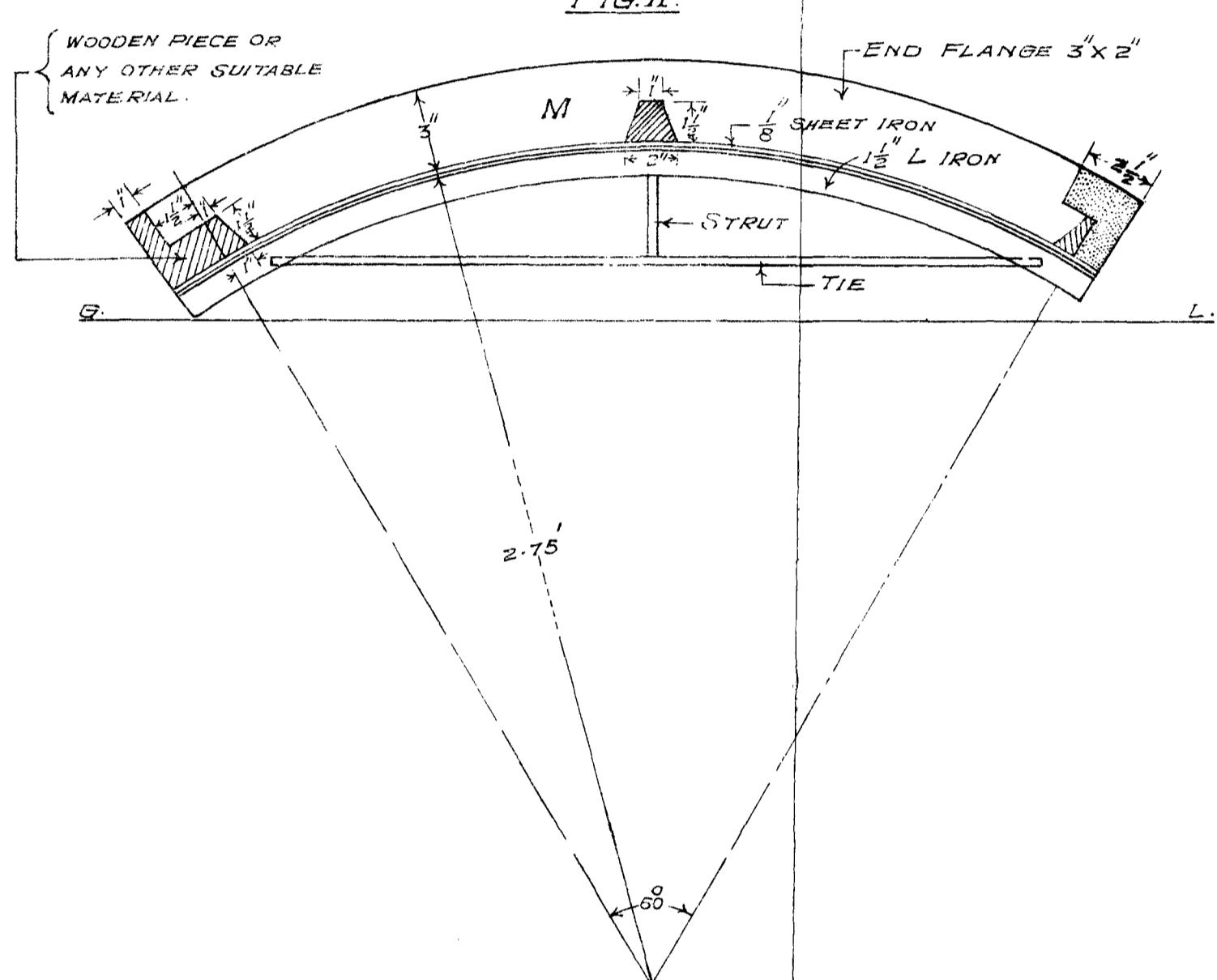
OUTER SIDE PLAN
FIG. V



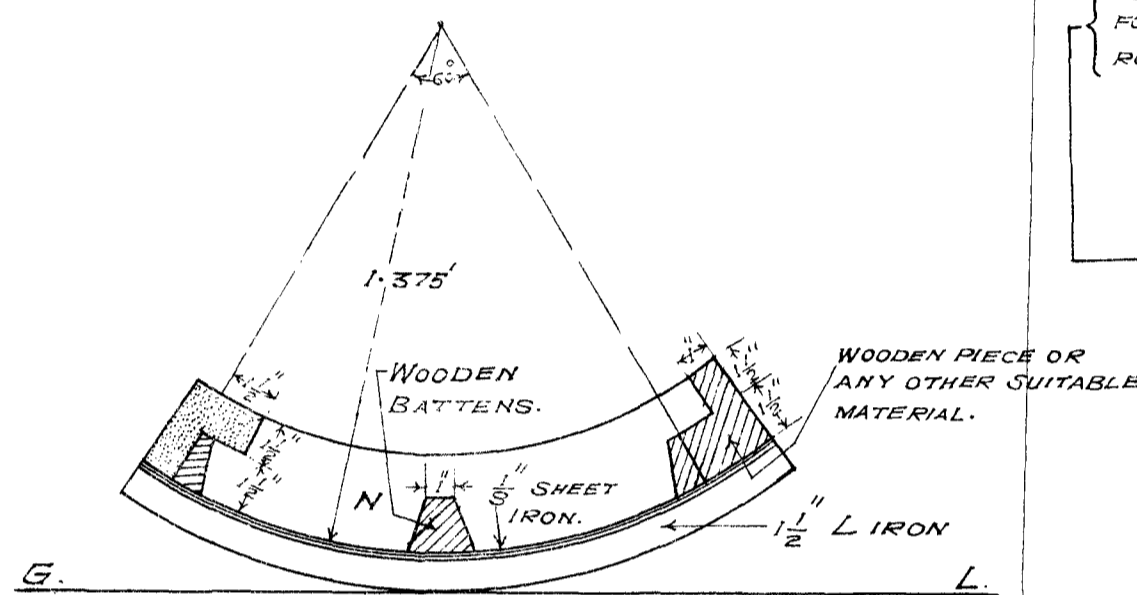
INNER SIDE PLAN
FIG. VII



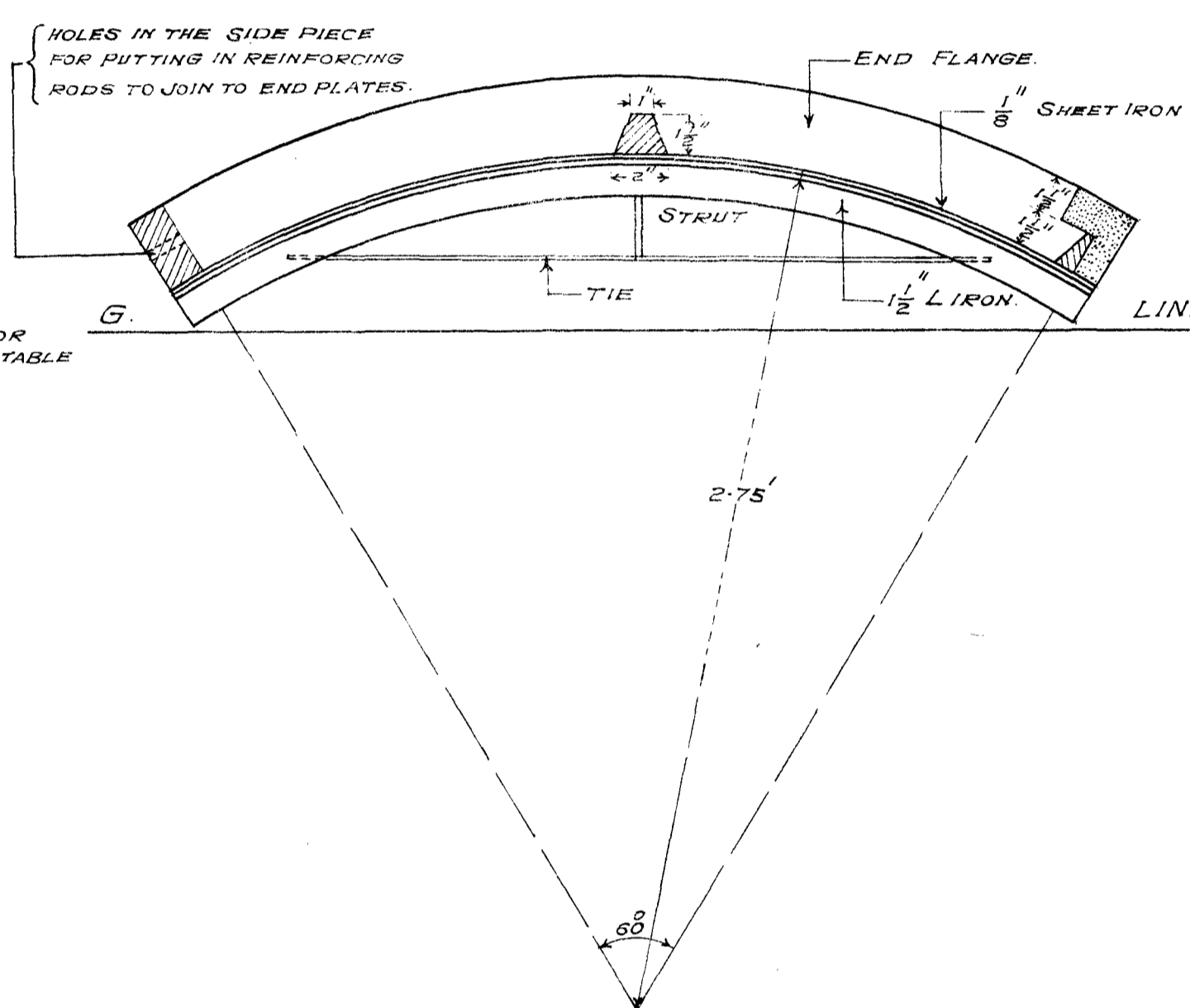
SECTION
FIG. II



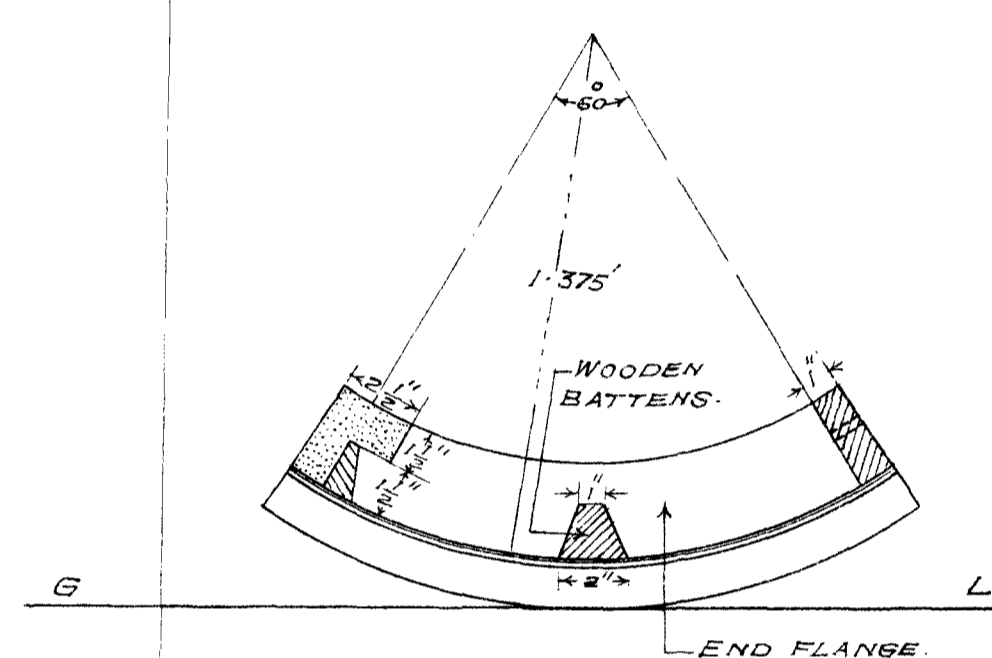
SECTION
FIG. IV



SECTION
FIG. VI

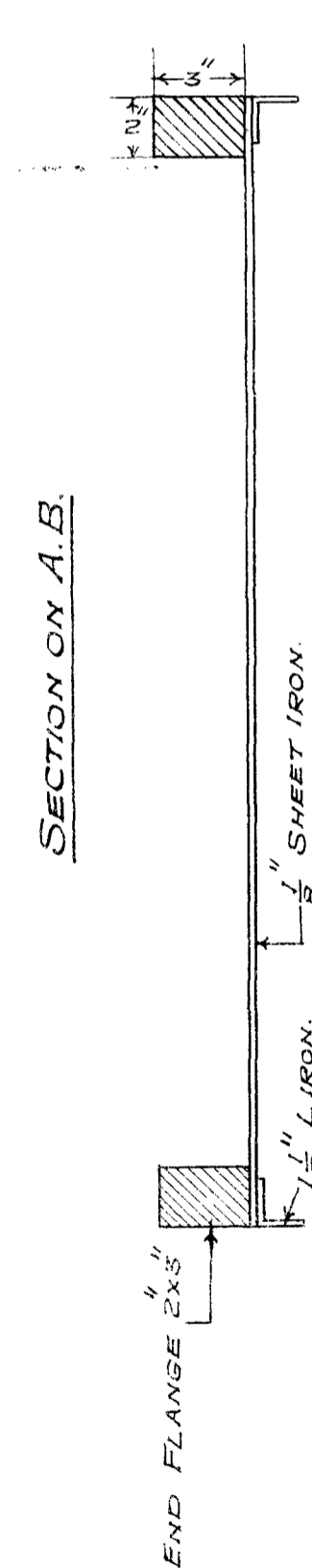
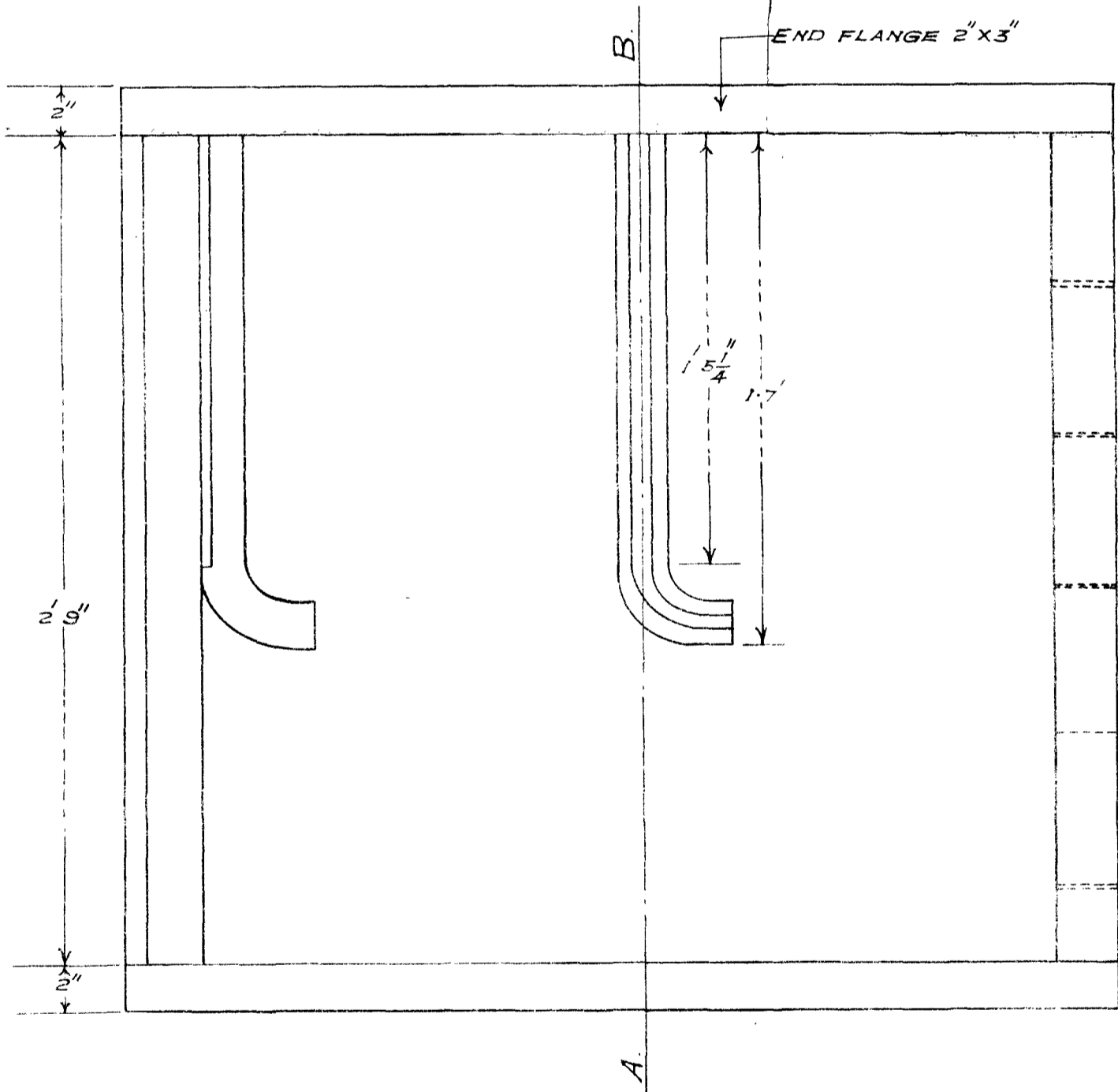


SECTION
FIG. VIII

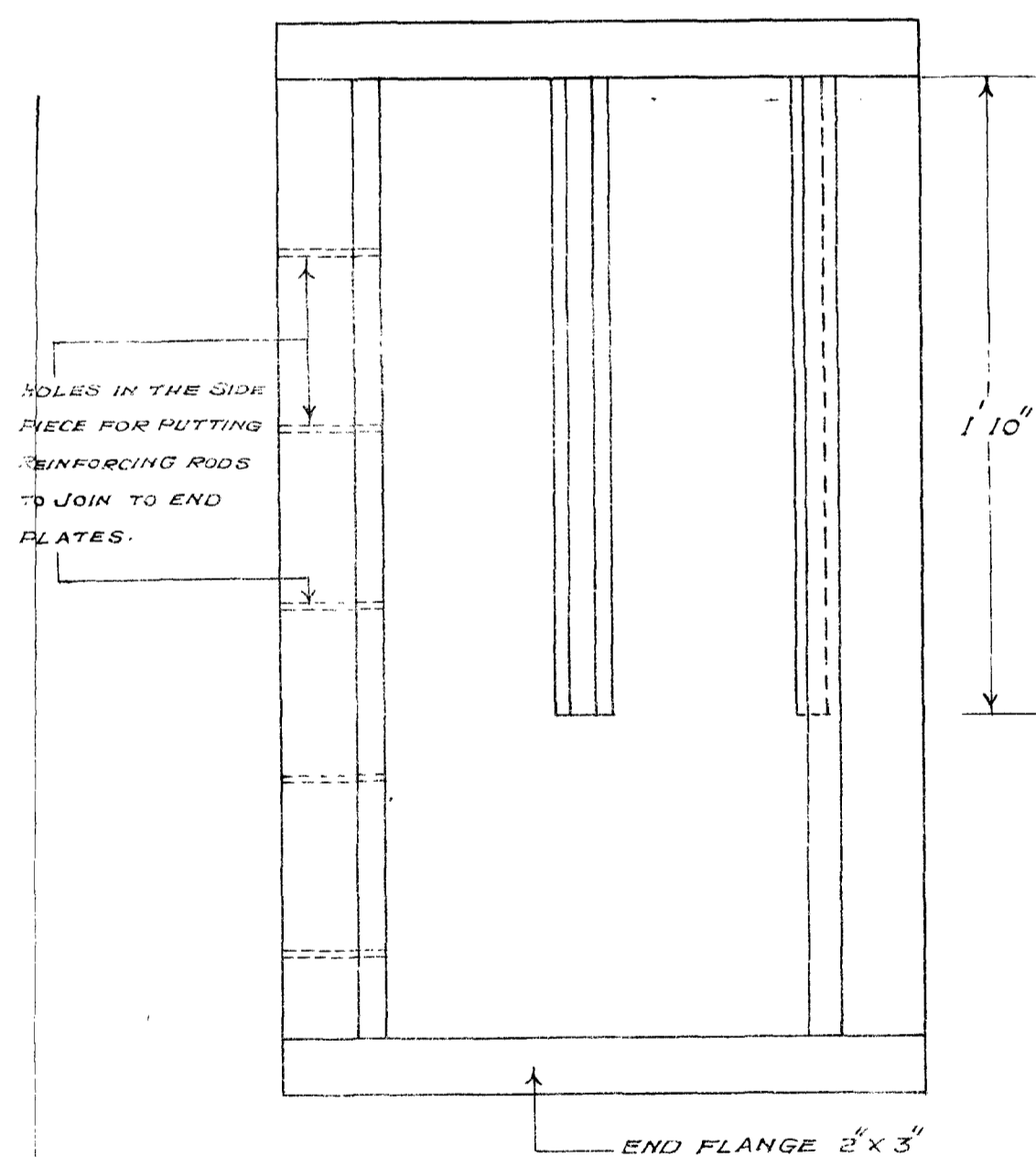


RIGHT HAND PORTION OF THE EDDY CHAMBER.

OUTER SIDE PLAN
FIG. IX

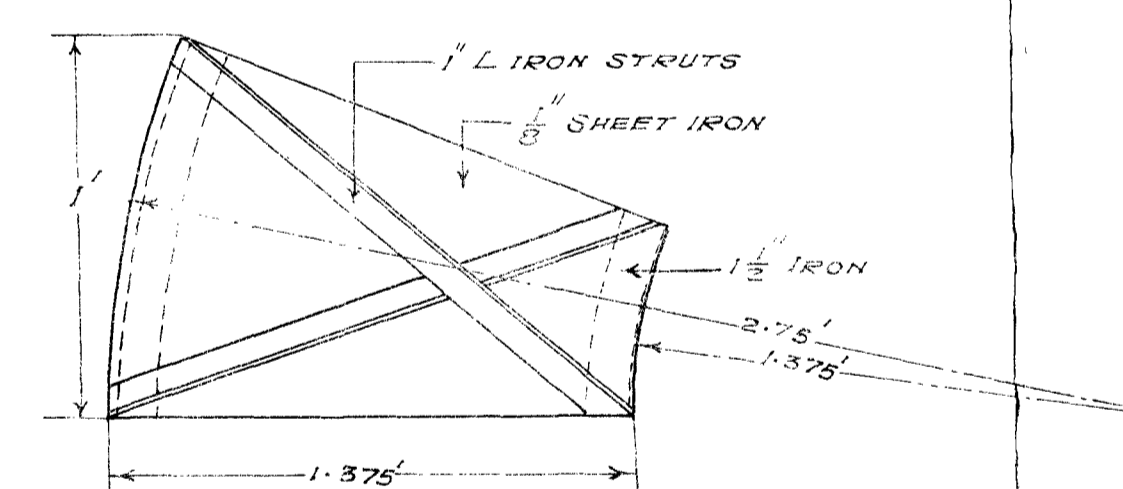


INNER SIDE PLAN
FIG. XI

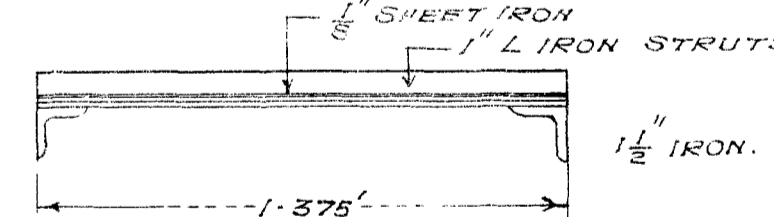


DETAILS OF THE DISTANCE PIECE

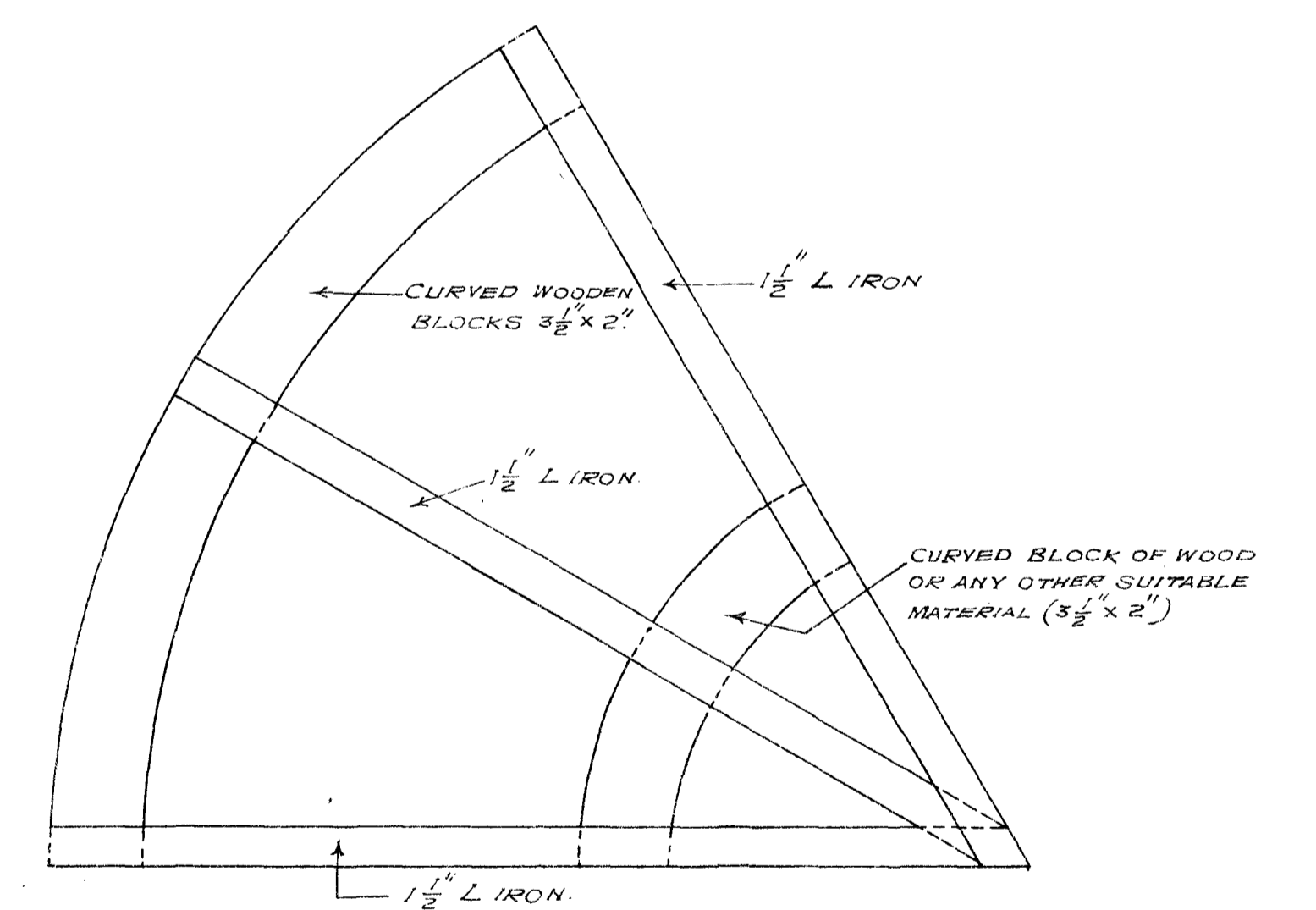
PLAN
FIG. XIII



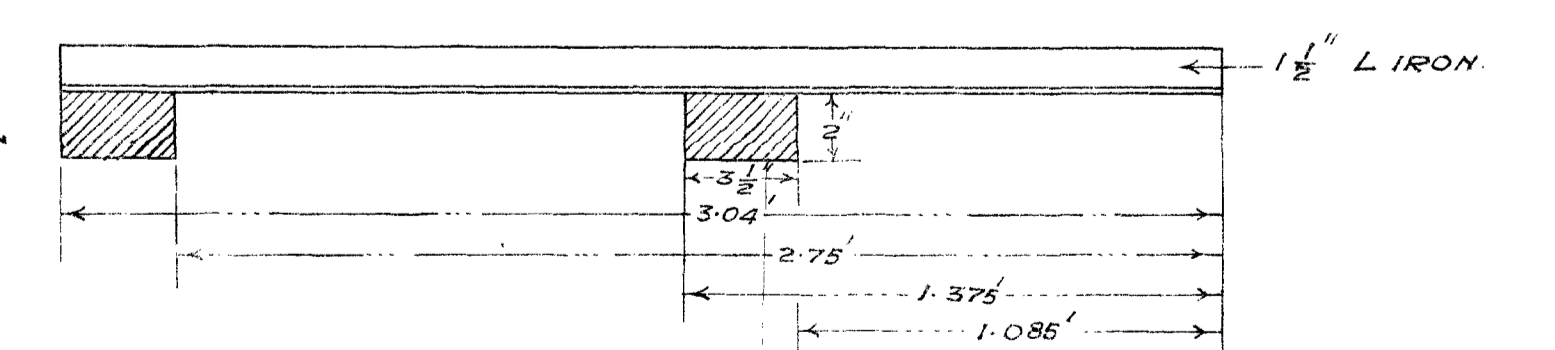
SECTION
FIG. XIV



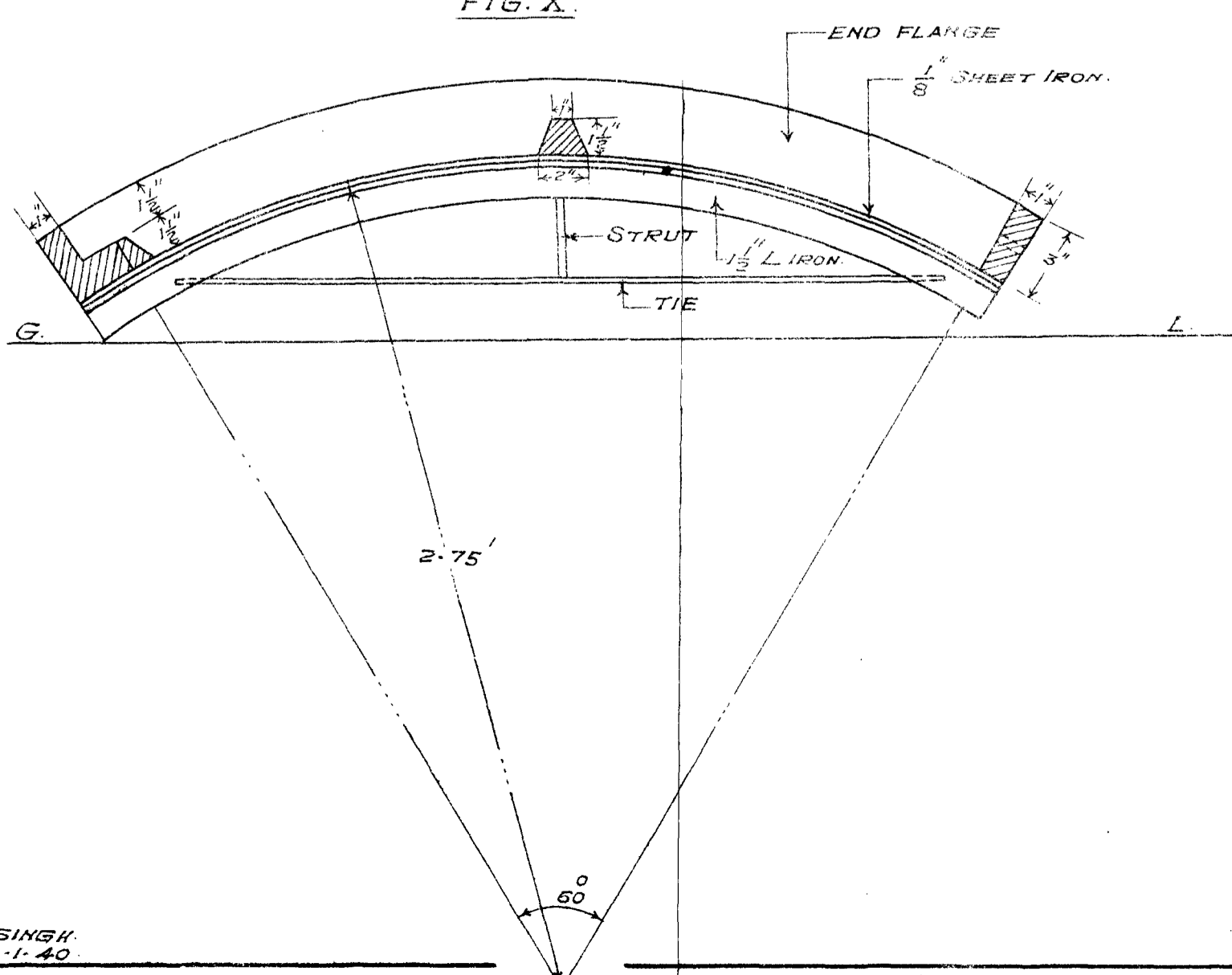
PLAN
FIG. XV



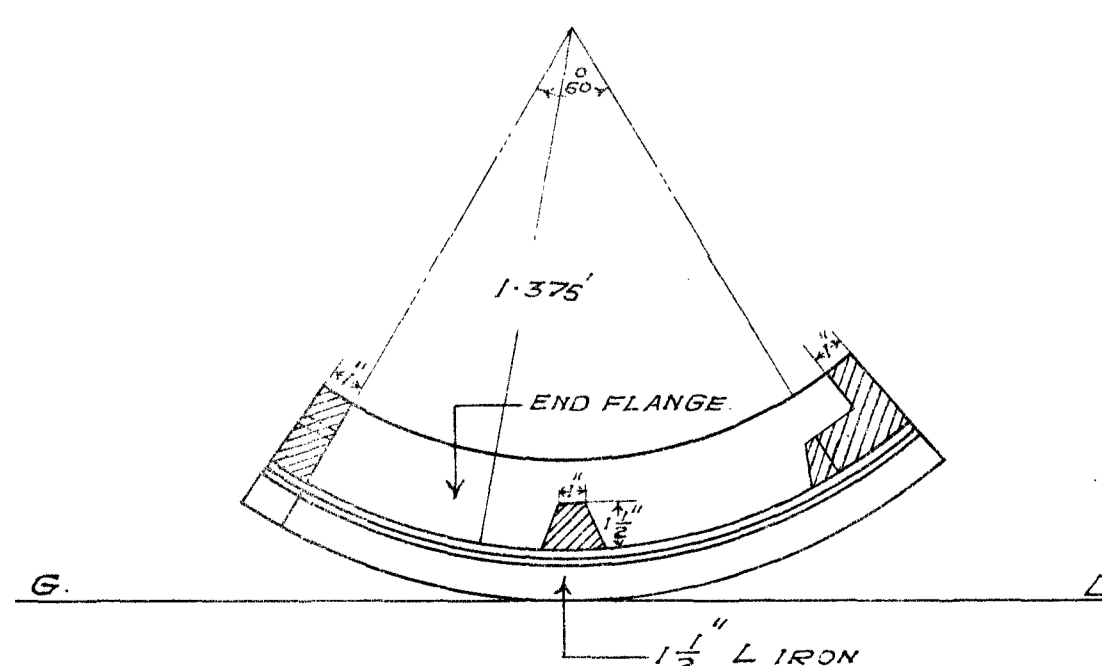
SECTION
FIG. XVI



SECTION
FIG. X

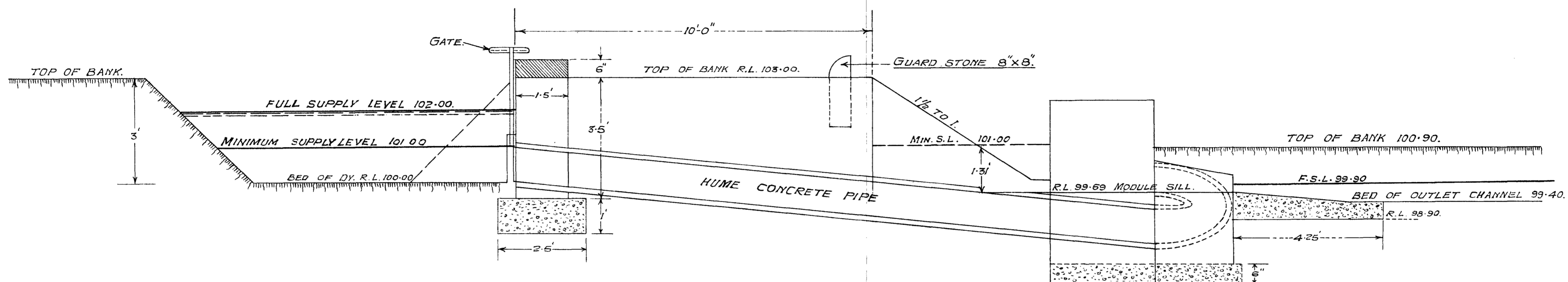


SECTION
FIG. XII

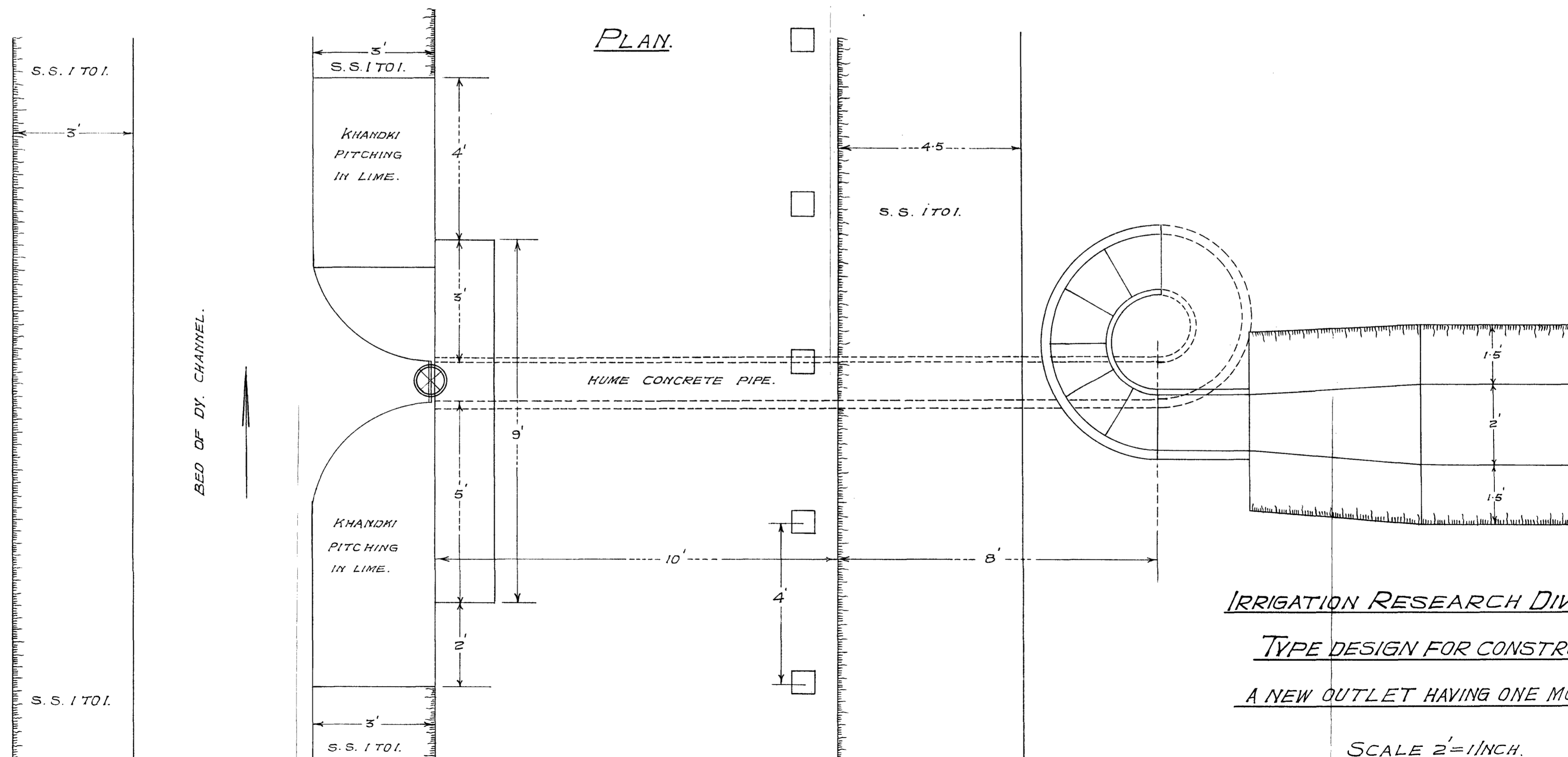


REMOVABLE PIECES SHOWN THUS [diagonal lines] [dotted lines]
NONREMOVABLE PIECES SHOWN THUS [diagonal lines]

LONGITUDINAL SECTION.



PLAN.



IRRIGATION RESEARCH DIVISION
 TYPE DESIGN FOR CONSTRUCTING
 A NEW OUTLET HAVING ONE MODULE.

SCALE 2" = 1' INCH.

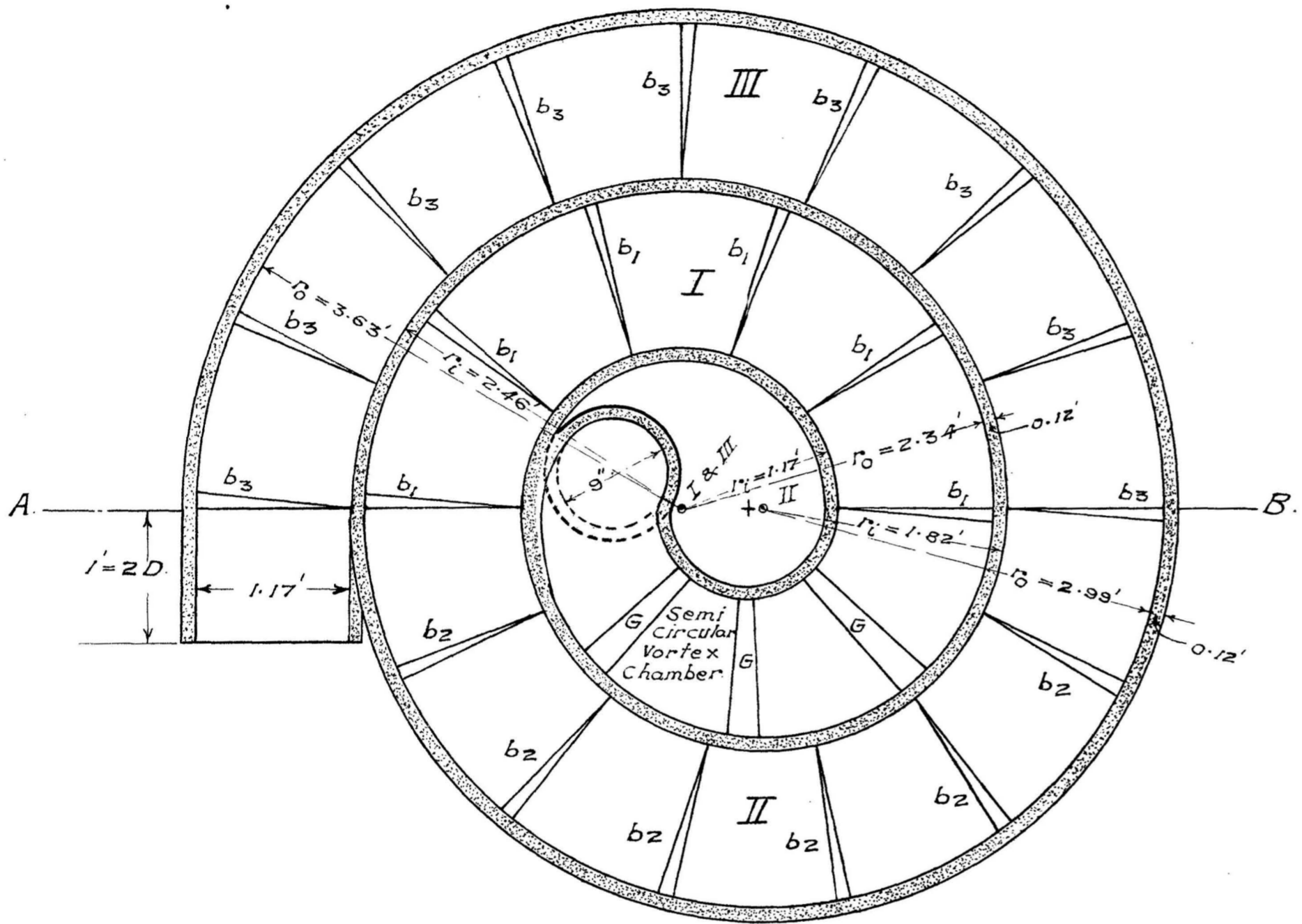
IRRIGATION RESEARCH DIVISION.
1 Cusec Spiral Gibb module (in R.C. concrete)

$$Q = c \sqrt{2g} r_0 \left[D \sqrt{h_0} \log_e m - \frac{h_0^{1.5}}{2} (m^2 - 1) \right]$$

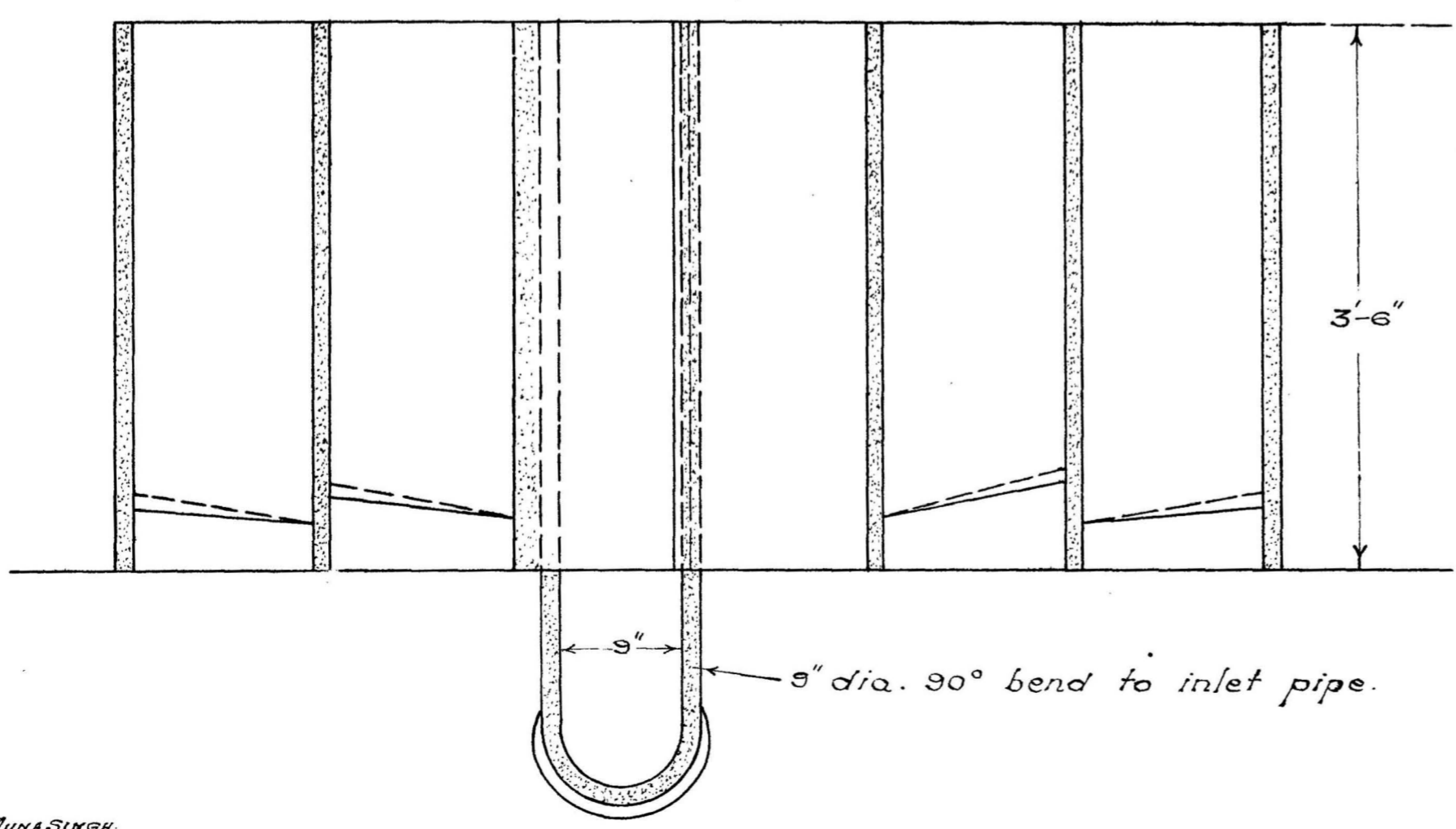
$$h_0 = \frac{D}{7}; m = \frac{r_0}{r_i}$$

scale: - 1" = 1"

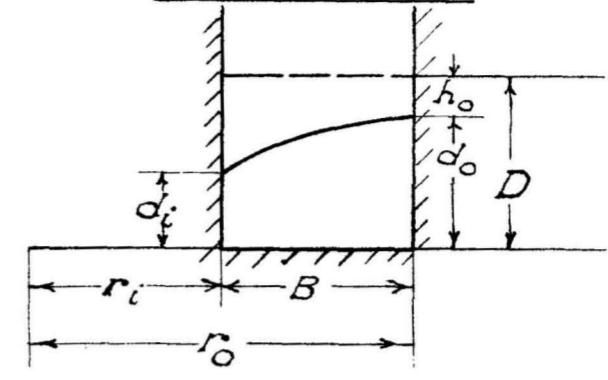
PLAN



SECTION ON A. B.



NOTATION

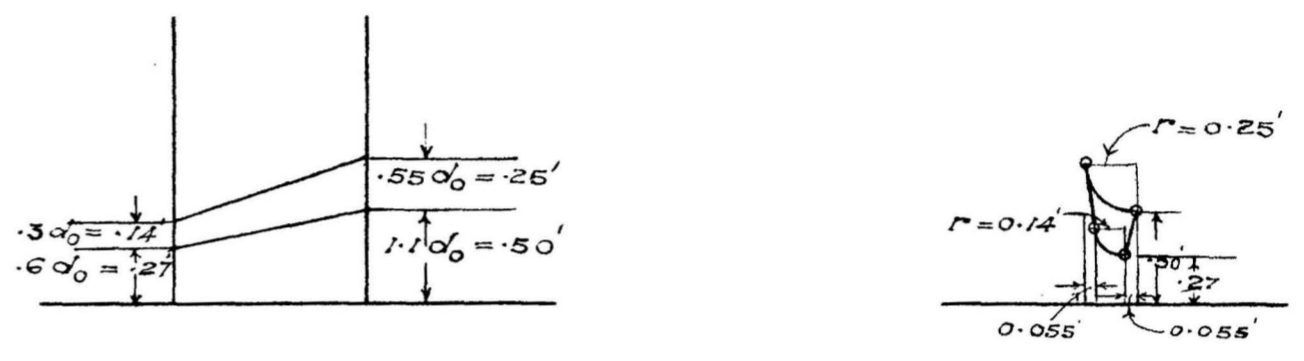


DETAILS.

FRONT ELEVATION.

GUIDES.

END VIEW.



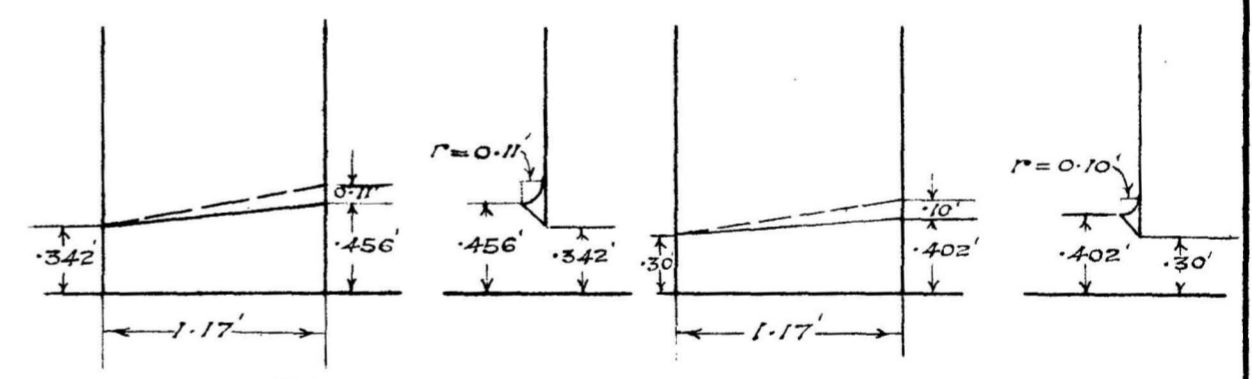
BAFFLES.

FRONT ELEVATION.

END VIEW.

FRONT ELEVATION.

END VIEW.



Semi-circle.	C coefficient of Q	r ₀	r _i	B = r ₀ - r _i	m = r ₀ /r _i	h ₀	d ₀	D	Distances between baffles along outer Circle.	No. of Baffles
I	0.758	2.34	1.17	1.17	2.0	.076	.456	.532	1.47	6
II	0.850	2.99	1.82	1.17	1.66	.067	.402	.469	1.34	7
III	0.935	3.63	2.46	1.17	1.48	.067	.402	.469	1.43	8

NOTE (PLAN)

- I & III is the centre of 1st & 3rd. Semi-circles.
- II is the centre of 2nd. semi-circle.
- + is the centre of the inner circle of Vortex chamber.

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 MADRAS :—Superintendent, Government Press, Mount Road, Madras.
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CONTENTS.

	PAGE.
Photos.	
PART I.—INTRODUCTION.	
1. Description	1
PART II.—EXPERIMENTS CARRIED OUT TO DETERMINE HOW FAR THEORETICAL ASSUMPTIONS ARE JUSTIFIED.	
2. Notation	3
3. General discharge formula for Gibb Modules	3
4. Definition of Range of Gibb modules	5
5. Object of experiments	5
6. Effect of adding baffles successively in the eddy chamber on the discharge and range	5
7. Effect on range of adding a bellmouth to the inlet pipe	7
8. Loss of head in the inlet pipe and curved rising pipe	8
9. Minimum working head in practice	9
10. Effect of fixing baffles at successively lower levels from entrance to exit of eddy chamber — to allow for frictional loss of head —	9
11. Effect on range of increasing the number of baffles in eddy chamber	10
12. Effect of increasing the length of arc of curvature through which water flows before entering the eddy chamber	11
13. Effect of increasing the spirals of the eddy chamber	12
14. Effect of varying $m(=r_0/r_1)$; h_0 ; D and B/D on range	12
15. Experiments with modules of 8 and 16 cusecs	15
16. Summary of results	16
PART III.—STANDARD DESIGNS OF MODULES.	
17. Design of the inlet pipe and the curved pipe	17
18. Spacing of baffles in eddy chamber	17
19. Length of exit flume or spout	17
20. Minimum working head	17
21. Maximum working depth	17
22. Standard designs of modules of various discharging capacities	18
PART IV.—METHODS FOLLOWED DURING 1928-31 IN REMODELLING AND MODULING DISTRIBUTARIES IN THE DECCAN, USING GIBB MODULES.	
23. Preface	19
24. Data	19
25. Size of outlets	19
26. Size of Gibb modules	20
27. Tail outlets	20
28. Minor distributaries	20
29. Losses in transit in a distributary	20
30. Remodelling an existing channel	21
31. Modules at distributary heads	21
32. ' Fixing ' and ' setting ' of Outlet modules	21
APPENDICES I TO IV	26
PLATES I TO V.	

EXPERIMENTS WITH GIBB MODULES.



356.—3 cusecs Gibb module being tested in the Measuring Tank (Gibb's standard design).



929.—One cusec Spiral module with 3 semi-circles.

EXPERIMENTS WITH GIBB MODULES.



← $m = \frac{r_o}{r_i} = 2.0$
 (Gibb standard design)

m=1.5

m=3.0

459.—0.3 cusec Gibb Modules : different designs.



16 Cusecs →
 module

3 Cusecs →
 module

1366.—8 and 16 cusecs Gibb modules (standard design) at the head of Distributary 8, Nira Left Bank Canal.

Note on the Theory, Design and Construction of Gibb . Modules which, without moving parts, give a constant discharge within working limits, irrespective of variations in upstream and downstream water levels.

The Note consists of :—

Part I.—Introduction.

Part II.—Experiments carried out to determine how far theoretical assumptions are justified.

Part III.—Standard designs of modules.

Part IV.—Methods followed during 1928-1931 in remodelling and moduling Distributaries in the Deccan, using Gibb modules.

PART I.—INTRODUCTION.

Although this Paper deals primarily with the use of Gibb modules in the Bombay Deccan, yet Parts I, II and III are general and even IV contains much of general application.

1. DESCRIPTION.

The module¹, named after its inventor Mr. A. S. Gibb, late Executive Engineer of the Irrigation Department, Punjab, gives an almost constant discharge over a considerable range, irrespective of the upstream and downstream water levels. Gibb's module is the only rigid module without any moving part.

Water enters this chamber through an inlet pipe, which delivers water to a 180° rising pipe in which free vortex flow is developed. It then enters the eddy chamber—see figure 1.

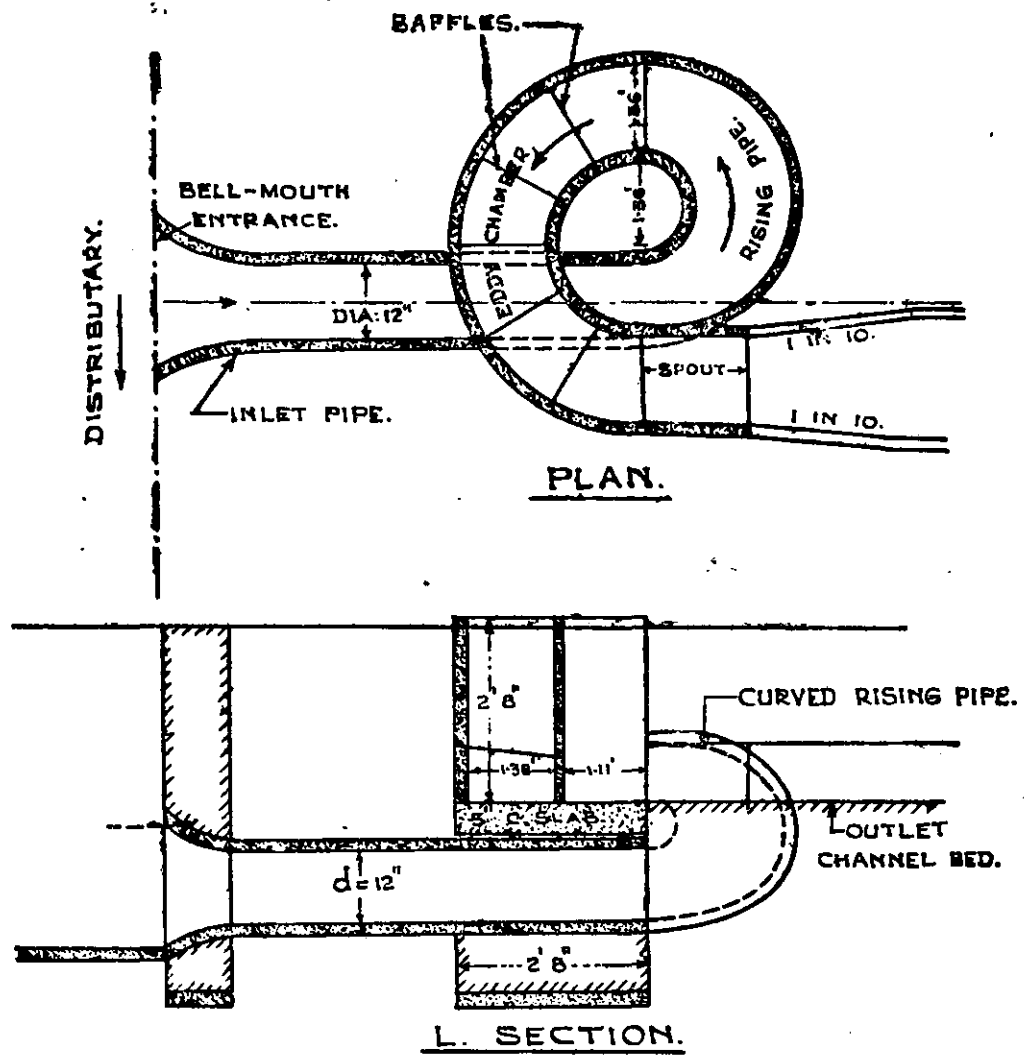
The water at the downstream end of the module discharges through a spout or flume into the outlet channel.

In free vortex flow, $\text{velocity} \times \text{radius} = \text{constant}$, for any filament. In this condition, the water at the outer circumference of the stream flows at a comparatively high level due to centrifugal force, and the surface slopes down towards the inner circumference—see figure 2 of Part II.

A series of baffles are fixed in the eddy chamber with their lower edges sloping at the required height above the sill of the module. If the head causing flow is in excess, the water banks up at the outer circumference of the eddy chamber and impinges against the baffles imparting an upward rotational direction of flow to the water which spins round in the compartment between two successive baffles and finally drops on the oncoming stream of water, thus dissipating excess energy. The action of baffles differs. In fact, except at maximum dissipation, some baffles are out of action and generally one baffle is much more effective than the others.

¹"Gibb's Module for irrigation channels, etc." Paper No. 13-A (Class A) published by the Irrigation Department, Punjab.

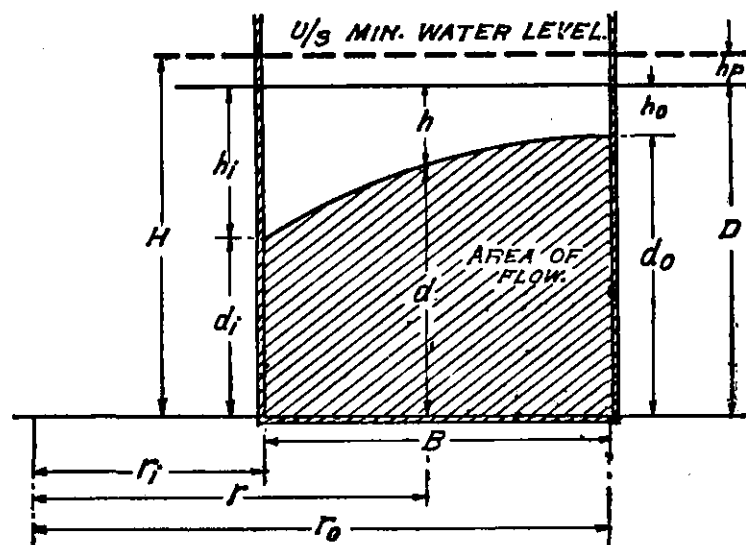
FIG:- 1, GIBB MODULE (3 CUSECS)
SCALE:- 1"=3'



PART II.—EXPERIMENTS CARRIED OUT TO DETERMINE HOW FAR THEORETICAL ASSUMPTIONS ARE JUSTIFIED.

2. NOTATION.

FIG. 2.



r_i = Radius of inner semi-circle of the eddy chamber.

r_o = Radius of the outer semi-circle.

d_i = Depth of water at inner circumference.

d_o = Depth of water at outer circumference.

h = Head causing flow, varying from h_o to h_i .

$h_p + D$ = Total difference of level measured from the minimum water level in the parent channel or distributary to the floor of the eddy chamber (*i.e.*, including head lost in inlet pipe = h_p).

m = r_o/r_i = Ratio of outer radius to inner radius.

Q = Discharge.

B = Width of eddy chamber = $r_o - r_i$.

3. GENERAL DISCHARGE FORMULA FOR GIBB MODULES.

Gibb's formula for discharge was

$$Q = r_o \sqrt{2g} (d_i + h_o)^{1.5} \left\{ \frac{m^2 - 1}{m^3} \log_e m + \frac{1}{m} \log_e m - \frac{m^2 - 1}{2m^3} \right\} \quad (1)$$

The way his formula was arrived at is explained in paras. 13, 14 and 15 of his Paper.

The formula is based on free vortex flow, in which the velocity at any point varies inversely as the radius; and by Bernoulli's theorem, the total energy head of all filaments is constant:—

[Total energy head = head due to velocity *plus* static head measured from the same datum.]

Gibb's formula held only for his standard design in which

$m = r_o/r_i = 2$, and

$\frac{h_o}{D} = 1/7$;

so a general formula was worked out as under :—

$$Q = \int_{r_1}^{r_0} V d r = \int_{r_1}^{r_0} \sqrt{2gh} d r$$

Now $r V = r_0 V_0$ or $r \sqrt{2gh} = r_0 \sqrt{2gh_0}$

$$\therefore h = h_0 \frac{r_0^2}{r^2} \text{ and } d = D - h = D - h_0 \frac{r_0^2}{r^2}$$

$$\begin{aligned} \therefore Q &= C \int_{r_1}^{r_0} \sqrt{2gh_0 \frac{r_0^2}{r^2} \left\{ D - h_0 \frac{r_0^2}{r^2} \right\}} dr \\ &= C r_0 \sqrt{2gh_0} \int_{r_1}^{r_0} \left\{ D/r - h_0 \frac{r_0^2}{r^3} \right\} dr \\ &= C r_0 \sqrt{2gh_0} \left[D \log \frac{r_0}{r_1} - h_0 r_0^2 \left\{ -\frac{1}{2r_0^2} + \frac{1}{2r_1^2} \right\} \right] \end{aligned}$$

Calling $r_0/r_1 = m$

$$Q = C r_0 \sqrt{2g} \left\{ D \sqrt{h_0} \log_e m - \frac{h_0^{3/2}}{2} (m^2 - 1) \right\} \quad (2)$$

and calling $h_0 = K D$

$$\begin{aligned} Q &= C r_0 \sqrt{2g} D^{3/2} \left\{ \sqrt{K} \log_e m - \frac{K^{3/2}}{2} (m^2 - 1) \right\} \quad (2A) \\ C &= 0.935 \end{aligned}$$

In Appendix I of this Paper, it is shown that Gibb's formula applies only when

$$h_0 = D_1/m^2 \text{ or } D_1 = h_0 m^2$$

$$\text{and } d_1 = D_1 \frac{(m^2 - 1)}{m^2} = h_0 (m^2 - 1)$$

and as $D = d_1 + D_1$

$$D = h_0 (m^2 - 1 + m^2) = h_0 (2m^2 - 1) \quad (3)$$

Gibb standardised

$$m = 2 \text{ or } D = 7 h_0$$

$$d_1 = 3D/7 = 3 h_0$$

$$\text{and } D_1 = 4D/7 = 4 h_0$$

and he designed on the assumption that the loss of head in the inlet pipe = h_0 . This is only true when the inlet pipe is of a standard length and design ; so that what he called Z or H is the assumed minimum working depth in the upstream channel over the sill of the module for a particular length and design of inlet pipe.

The total energy head available over the module sill in the eddy chamber is 7/8ths of Gibb's H , and is called D and $= d_0 + h_0 = d_1 + h_1$.

The following relationships should be clearly borne in mind :—

$$\begin{aligned} d_1 &= D - h_1 \\ &= D - h_0 m^2 \\ &= D - K D m^2 \\ &= D (1 - K m^2) \end{aligned}$$

Gibb stated that correct free vortex conditions are established provided the circular upstream pipe completes a curve subtending an arc of 120° or more.

4. DEFINITION OF RANGE OF GIBB MODULES.

Although the Paper is only being published in 1940, yet the work on which it is based was done—chiefly by Rao Sahib Joglekar—during 1927 to 1930 under the direction of the Senior author.

The standard variation from modularity then laid down was ± 3 per cent. ; and "range" was defined as the difference between the maximum and minimum depths of water upstream of the module within which the discharge varied by less than ± 3 per cent.

5. OBJECT OF EXPERIMENTS.

The object of experiments was to ascertain—

- (1) the effect of adding baffles successively in the eddy chamber on discharge and range ;
- (2) the effect of adding a bellmouth to the inlet pipe ;
- (3) actual loss of head in inlet pipe and curved rising pipe ;
- (4) minimum working head in practice ;
- (5) factors affecting range, *viz.*,
 - (a) fixing baffles at successively lower levels from entrance to exit of eddy chamber,
 - (b) increasing the number of baffles in eddy chamber ;
 - (c) increasing the length of arc of curvature through which water flows before entering the eddy chamber ;
 - (d) increasing the spirals of the eddy chamber ;
 - (e) varying m (r_o/r_i) ; h_o and D

It must be clearly understood that these experiments were only carried out with field accuracy using field modules and the variation in discharge considered permissible for practical purposes was ± 3 per cent.

6. EFFECT OF ADDING BAFFLES SUCCESSIVELY IN THE EDDY CHAMBER ON THE DISCHARGE AND RANGE.

In the standard design of 3 cusecs Gibb module, there are six baffles.

Figure 3 shows the cross section at the junction of curved pipe and the eddy chamber.

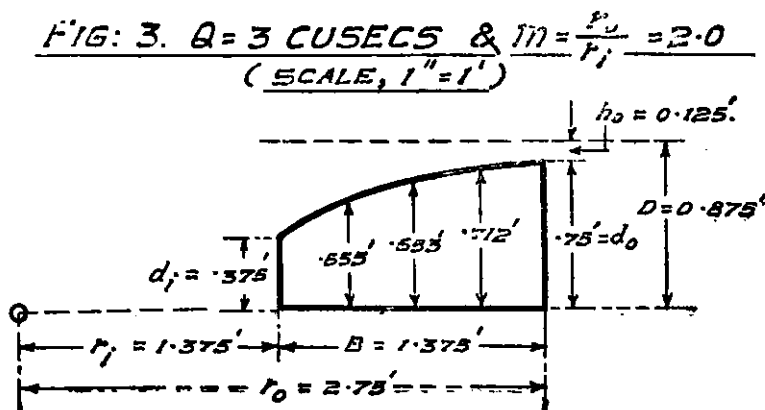
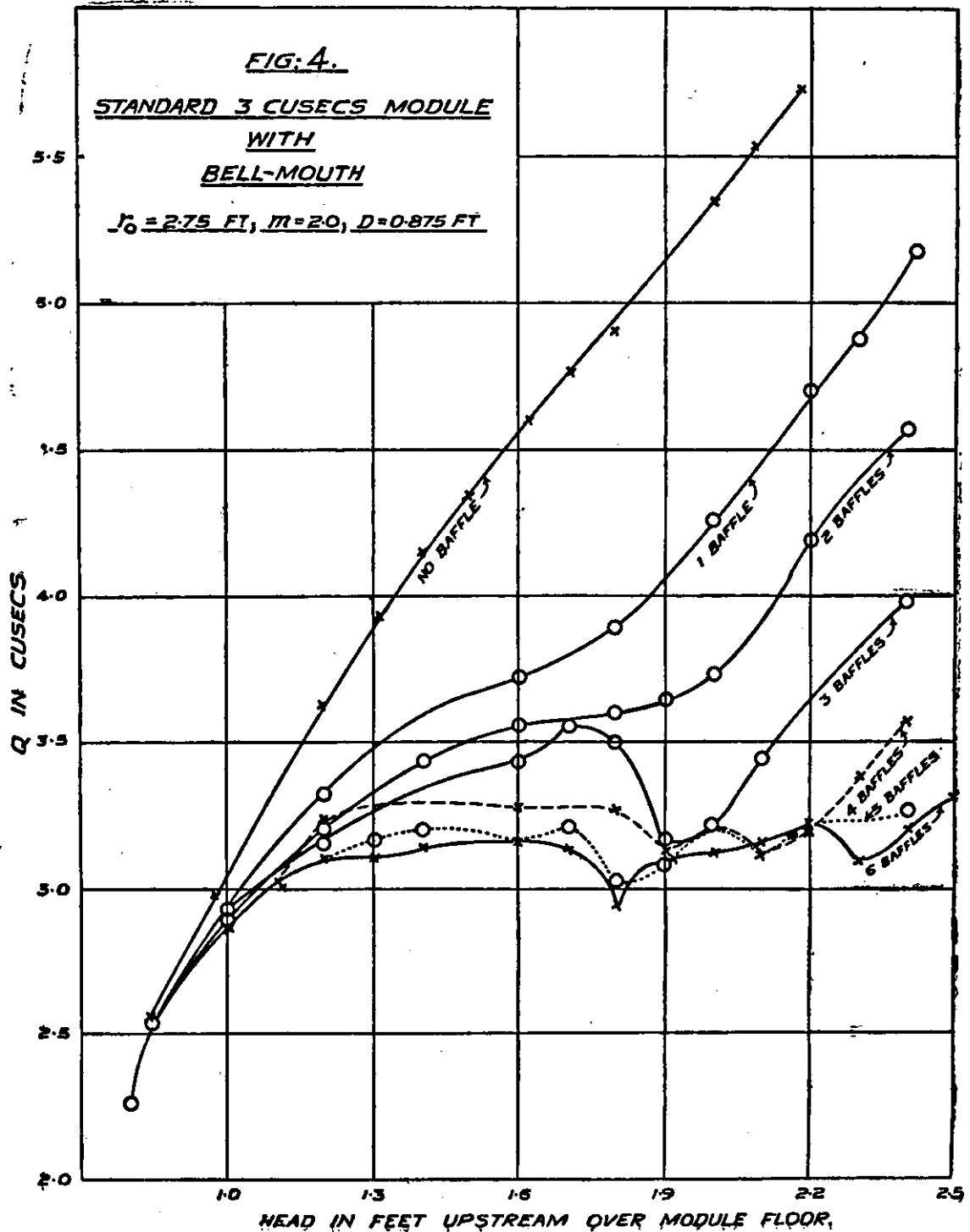


Photo 356 shows a 3 cusec Gibb module being tested.

Discharges were observed with various water levels upstream ; both without baffles and after adding baffles successively. Results are shown in figure 4, and table 1 shows the head killed by the addition of each successive baffle. (The discharge scale in figure 4 is exaggerated to show differences clearly.)

TABLE 1.

No. of baffles in the eddy chamber.	Mean discharge (cusecs).	Range of u/s water levels over module floor with ± 3 per cent. variation in Q (ft.).	Difference of each successive baffle (ft.)
(1) 1	3.7	1.38 to 1.72=0.34	
(2) 1 and 2	3.55	1.45 to 1.93=0.48	0.14
(3) 1, 2 and 3	3.25	1.20 to 1.45= .25 1.85 to 2.08= .23	Nil
(4) 1, 2, 3 and 4	3.20	1.15 to 2.27=1.12	0.64
(5) 1, 2, 3, 4 and 5	3.10	1.10 to 2.34=1.24	0.12
(6) 1, 2, 3, 4, 5 and 6	3.10	1.10 to 2.40=1.30	0.06



With only the 1st and 2nd baffles, the discharge was not modular. Discharge began to be modular with the 3rd baffle added. The 4th baffle was most effective, as the range increased to 1.12 ft. Adding a 5th and 6th baffle increased the range to 1.30 ft. As the above results showed that 3rd and 4th baffles were the more effective; experiments were done with these two baffles. These alone were not, however, effective; but became effective when the 1st baffle was added—see figure 5 and table 2.

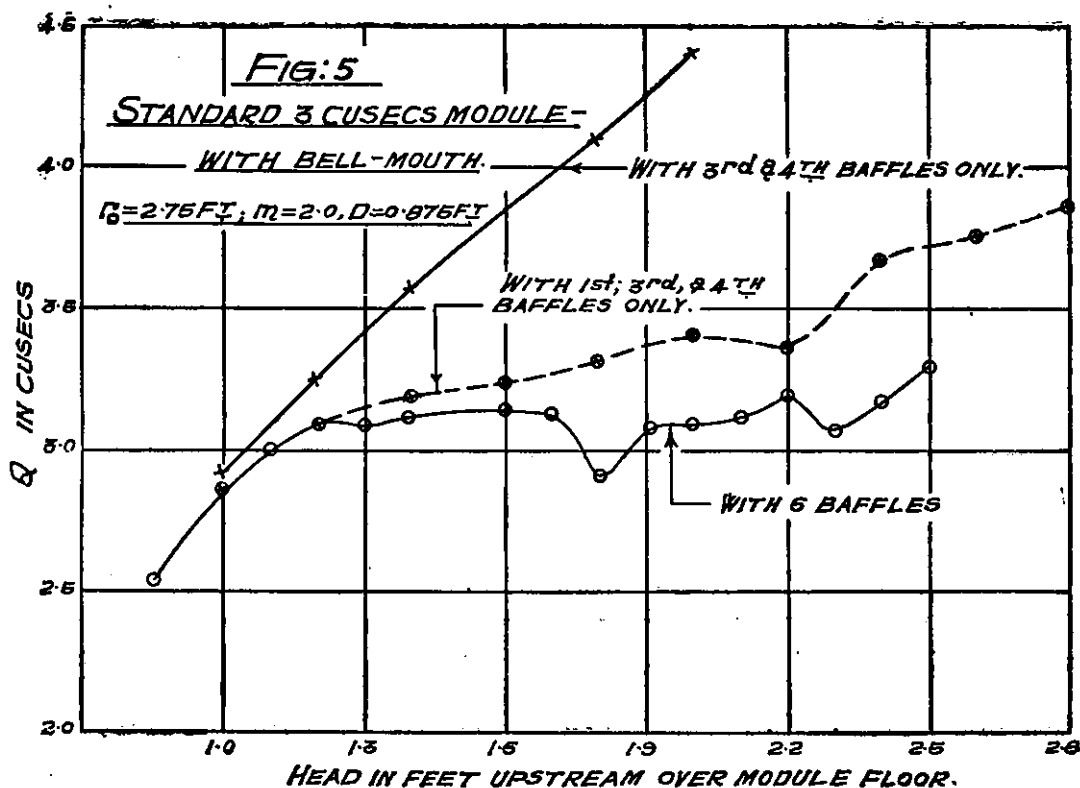


TABLE 2.

No. of baffles in the eddy chamber.	Mean discharge (cusecs).	Range of u/s W. L. s, over module floor with ± 3 per cent. variation of Q (ft.)	Difference (ft.).
(1) 3rd and 4th	3.57	1.36 to 1.55	0.19
(2) 1, 3 and 4th	3.30	1.5 to 2.26	0.76
(3) 1 to 6	3.10	1.1 to 2.4	1.30

7. EFFECT ON RANGE OF ADDING A BELLMOUTH TO THE INLET PIPE.

Experiments described in para. 6 were carried out with a 3 cusec module with a bellmouth at the inlet to the pipe from the distributary—*vide* plate I. Experiments were repeated after removing the bellmouth.

Experiments were also done with 4.5 cusecs module without a bellmouth and with a bellmouth.

Table 3 shows the effect of bellmouth on range. Figure 6 shows the dimensions of the standard bellmouth in terms of the diameter of the inlet pipe.

FIG. 6.
BELL MOUTH PIPE

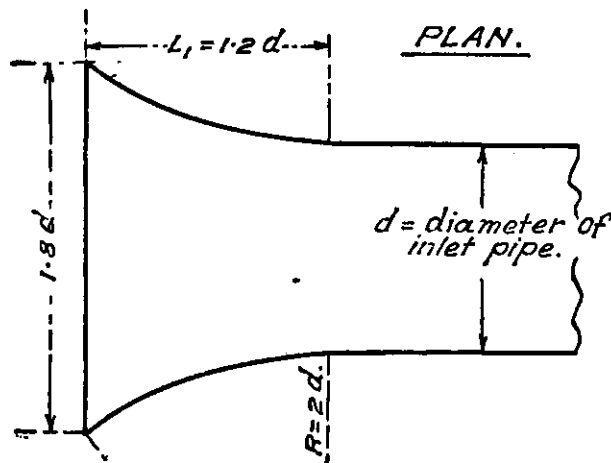


TABLE 3.

	Range of u/s water levels over module floor with ± 3 per cent. variation in discharge.	
	Without a bellmouth.	With a bellmouth.
3 cusecs module	1.20 to 2.40 = 1.20'	1.10 to 2.40 = 1.30'
4.5 cusecs module	1.46 to 2.60 = 1.14'	1.18 to 2.82 = 1.64'

(The range for 3 and 4.5 cusecs Gibb Modules as stated by Gibb = 1.5' and 1.8' respectively. It is not known whether he used bellmouths.)

With a bellmouth, the range of the module was increased considerably and less head was required to attain modularity—see table 4—

TABLE 4.

$m = r_o/r_i = 2.0 ; h_o/D = 1/7$

	3 cusecs module.	4.5 cusecs module.
(1) D in ft.	0.87	0.85
(2) Minimum depth of water upstream over module floor (ft.)—		
(a) without a bellmouth	1.20	1.46
(b) with a bellmouth	1.10	1.18
(3) Loss of head in inlet and curved pipes (ft.)—		
(a) without a bellmouth	0.33	0.61
(b) with a bellmouth	0.23	0.33

8. LOSS OF HEAD IN THE INLET PIPE AND CURVED RISING PIPE.

Pressures were observed in the 3 cusecs Gibb module with the minimum upstream water level of 1.105 ft. over module floor, at which the modular action began, at—

- (i) the junction of the bellmouth and the inlet pipe,

- (ii) the junction of the inlet pipe and the curved pipe, and
 (iii) the junction of the curved pipe with the eddy chamber.

Total energy=energy head due to pressure *plus* energy head due to velocity.
 Table 5 shows the results.

TABLE 5.

	Junction of bellmouth and inlet pipe.	Junction of inlet pipe and curved pipe.	Junction of curved pipe and eddy chamber.
(1) \bar{V} (f/s)	3.82	3.82	3.48
(2) $h_v (= \bar{V}^2/2g)$ (ft.)	0.23	0.23	0.19
(3) Mean observed pressure head in ft.	0.785	0.755	0.735
(4) Energy (ft.) (total of items 2 and 3)	1.015	0.985	0.925

Total loss of head= $1.105 - 0.925$
 $= 0.18$ ft.

- (i) Loss of head in bellmouth $= 1.105 - 1.015$
 $= 0.09$ ft. or 50 per cent. of total loss.
 (ii) Loss of head in inlet pipe $= 1.015 - 0.985$
 $= 0.03'$ or 16.6 per cent. of total loss.
 (iii) Loss of head in curved pipe $= 0.985 - 0.925$
 $= 0.06'$ or 33.4 per cent. of total loss.

With this data, the loss of head for other sizes of modules was calculated as shown in Appendix III.

9. MINIMUM WORKING HEAD IN PRACTICE.

Minimum working head=minimum water level upstream at which modular action begins — maximum water level downstream which just does not affect discharge.

This includes loss of head in bellmouth, inlet pipe and curved pipe.

Experiments were carried out with 0.3 ; 1 ; 2 ; 3 ; 8 and 16 cusecs modules and results are shown in Table 6. In the case of 8 and 16 cusec modules, the spout had 1 in 10 divergences downstream.

In these experiments, the upstream water level was kept at a minimum value when modular action just began, and the downstream water level was then raised till the upstream level was just not affected. The difference of these two gave the minimum working head.

According to Gibb, the maximum depth downstream above the module floor $= 4/7 D$ or $0.56 D$. The observed maximum water level downstream above module floor varied between $0.57 D$ to $0.65 D$, the mean value being $0.61 D$ —see column 8 of Table 6. Better recovery of head was obtained when 1 in 10 diverging walls were added to the spout, the maximum depth downstream then being $0.70 D$.

10. EFFECT OF FIXING BAFFLES AT SUCCESSIVELY LOWER LEVELS FROM ENTRANCE TO EXIT OF EDDY CHAMBER—TO ALLOW FOR FRICTIONAL LOSS OF HEAD.

Baffles were fixed in the 3 cusecs module at successively lower levels from entrance to exit of eddy chamber, the idea being to neutralise the loss of head due to friction and thus increase the range by making baffles more effective. The discharge curves are shown in figure 7 and table 7 shows results.

13. EFFECT OF INCREASING THE SPIRALS OF THE EDDY CHAMBER.

According to Gibb, the range is increased as the number of spirals of the eddy chamber is increased, *i.e.*, the range of a spiral module consisting of 3 semi-circles is three times the range of a 'single semi-circle' module.

Experiments were carried out with a 1 cusec, three spiral, module to test this. Plate V shows the design of a 1 cusec, spiral, reinforced cement concrete module. Details of the design are given in Appendix IV.

A semi-circular vortex chamber was provided upstream of the 1st semi-circle, containing guides to create free vortex flow. Water was led from the leading channel through a 9" diameter pipe and 9" (90°) bend into the vortex chamber. Guides and baffles were of iron plates and the rest of the module was built in 'Nofrange' concrete according to design shown in plate V—see photo 929.

Figure 10 shows the discharge curve. The range was found to be 1.32 ft. with mean $Q=0.85$ cusec.

The range of a single semi-circle, standard, 1 cusec Gibb module, shown in Plate I, was 0.93 ft. so the *range of the three-spiral module was only 1.42 times that of a single semi-circle standard module.*

Another experiment was carried out in which the two outer semi-circular eddy chambers were removed. The range was 0.95 ft. with mean $Q=1.12$ cusecs—which was nearly the same as the range of the standard 1 cusec module, *viz.*, 0.93 ft.

The minimum working head in the spiral module (with three semi-circles) was 0.55 ft. against 0.36 ft. of the standard module. The spiral modules are more costly and the guides had to be very carefully fixed.

14. EFFECT OF VARYING $m (=r_o/r_i)$; h_o ; D AND B/D ON RANGE.

The general discharge formula is

$$Q = \sqrt{2g} r_o [D\sqrt{h_o} \log_e m - \frac{h_o^{1.5}}{2} (m^2 - 1)]$$

In order to determine which of the factors, *viz.*, r_o , h_o , m ; D; B/D affect the range, experiments were carried out with small size modules of 0.3 cusec—to get quick results at a small cost—*vide* photo 459.

(a) m , r_o , B and h_o were kept constant and D (and hence h_o/D), B/D and Q were varied.

TABLE 9.

$m=2$; $r_o=1$ ft.; B=0.5 ft. and $h_o=0.053$ ft.

Expt. No.	D (ft.)	B/D	h_o/D	Mean Q (cusec).	Range with ± 3 per cent. variation in Q.
1	0.260	1.92	1/4.9	0.16	0.37
2*	0.368	1.36	1/7	0.31	0.61
3	0.398	1.26	1/7.51	0.35	0.52
4	0.477	1.15	1/9	0.46	0.50
5	0.583	0.86	1/11	0.67	0.42

* Gibb's Standard design—*vide* figure 11.

In this Series, the range was a maximum in experiment 2 in which dimensions of the module were according to Gibb's standard, *viz.*, $m=2$ and $h_o/D=1/7$.

(b) In this Series, r_o was kept constant and m , D and h_o/D were varied, *vide* photo 459,

FIG. 10 EXPERIMENTS WITH 1 CUSEC
SPIRAL GIBB MODULE.

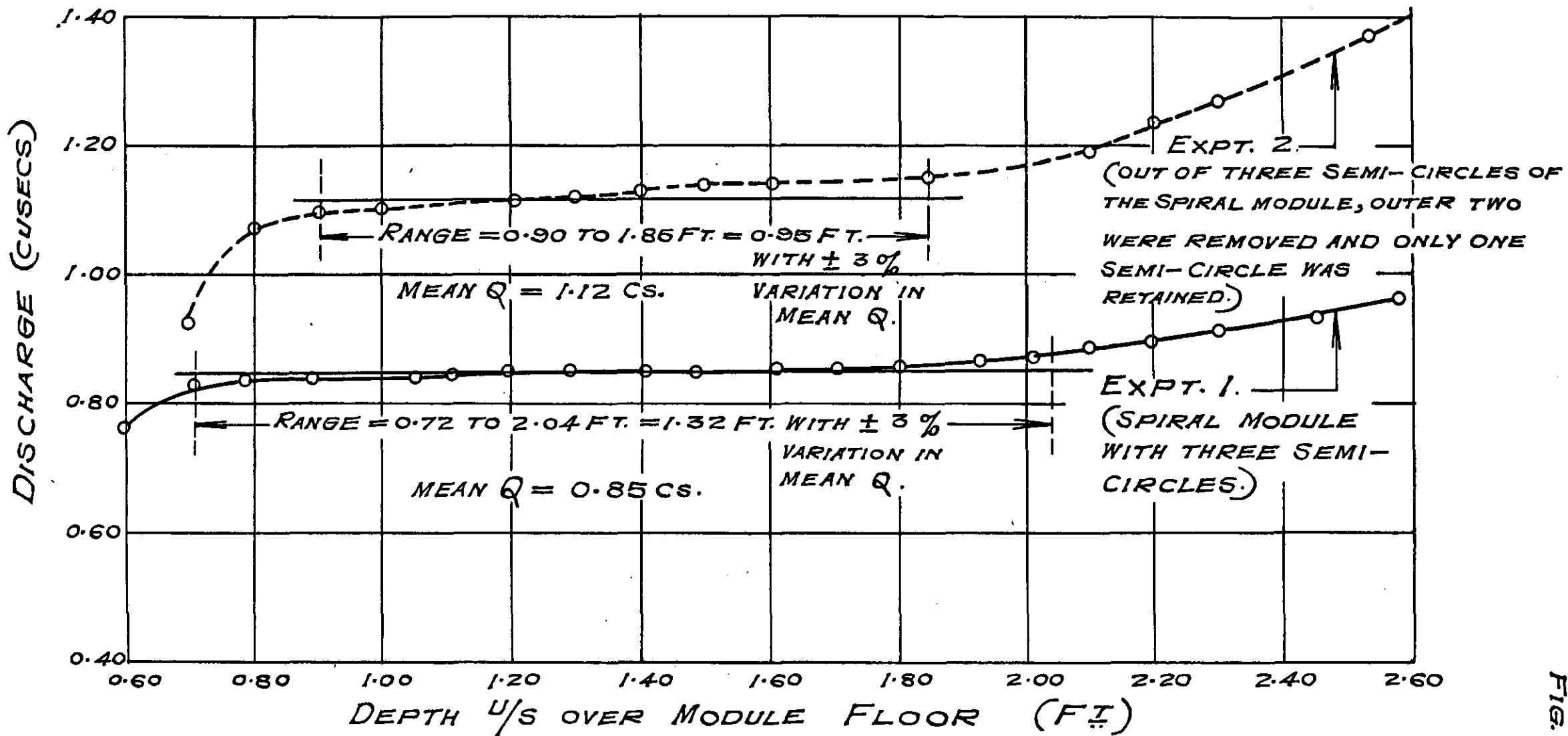


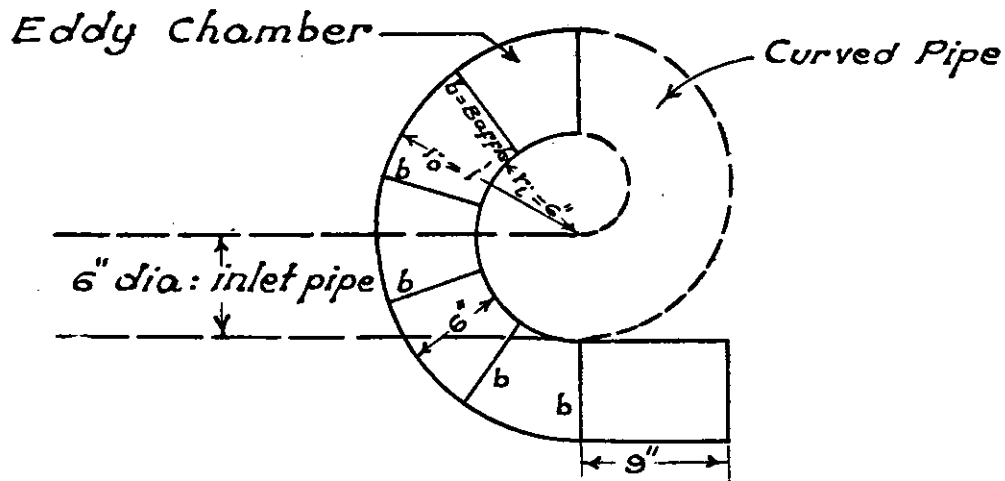
FIG. 10

IRRIGATION RESEARCH DIVISION
0.3 CUSEC GIBB MODULE.

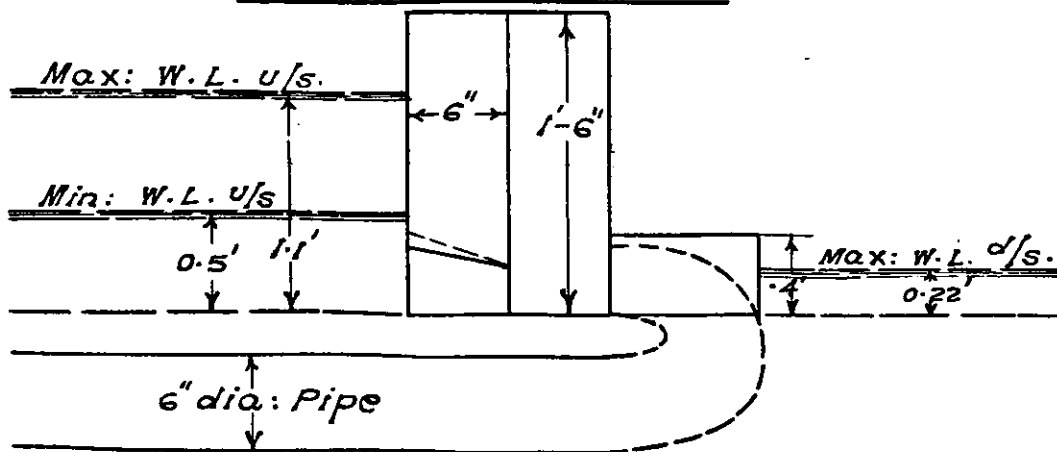
No 505

FIG. II

PLAN
SCALE:- 1"=1'



SECTIONAL ELEVATION



JUNCTION OF CURVED PIPE WITH EDDY CHAMBER.
SCALE:- 6"=1'

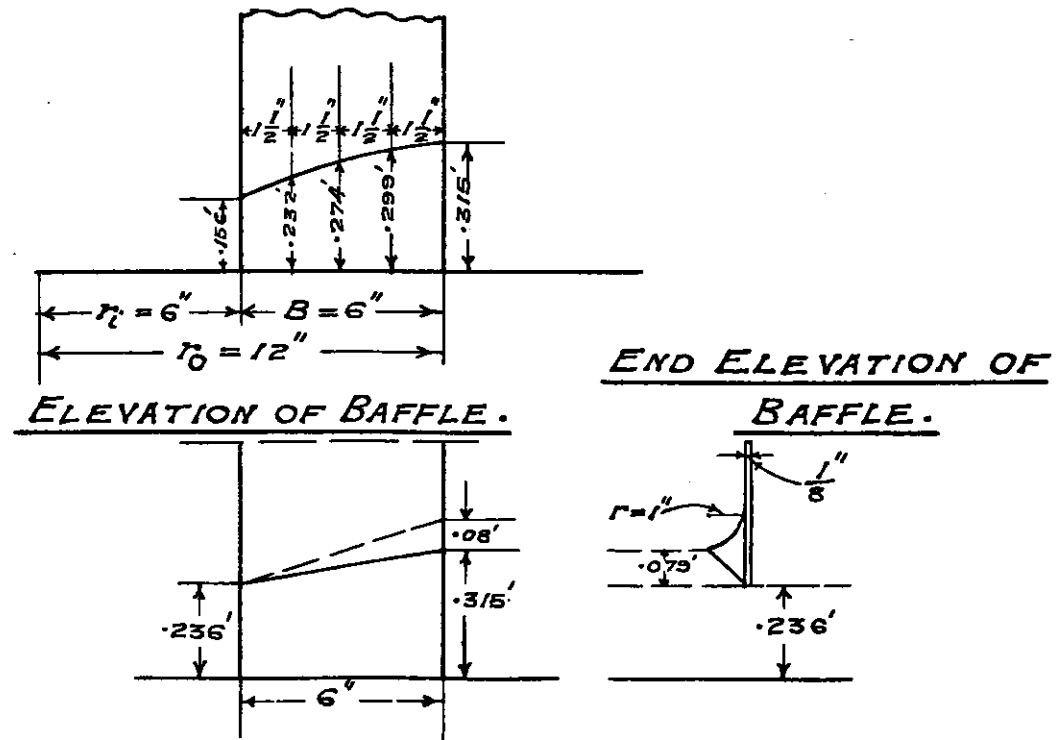


TABLE 10.

Experiment No.	6	2 of Table 9	7
m	1.5	2.0	3.0
r _o (ft.)	1.0	1.0	1.0
B (ft.)	0.333	0.5	0.667
D (ft.)	0.511	0.368	0.306
B/D	0.65	1.36	2.18
h (ft.)	0.053	0.053	0.028*
h ^o /D	1/9	1/7	1/10.92
Mean Q (cusecs)	0.345	0.310	0.335
Range in ft. with ± 3 per cent. variation in Q.	0.40	0.60	0.42

[* The module with m=3.0 (experiment 7) could not be designed with h_o=0.053 ft., as a negative depth was obtained at the inner circumference; hence h_o was assumed to be 0.028 ft.]

The range was a maximum with Gibb's standard design.

(c) In this series, the effect of B/D on range in modules with m=2.0 was tested. Gibb did not standardise B/D ratios and according to him, modules having the same discharging capacity, but with larger B/D ratios should have a bigger range than with lesser B/D ratio.

TABLE 11.

Experiment No.	2 of Table 9	8
m	2.0	2.0
r _o (ft.)	1.0	1.25
B (ft.)	0.5	0.625
D (ft.)	0.368	0.302
B/D	1.36	2.05
h _o (ft.)	0.053	0.043
h _n /D	1/7	1/7
Mean Q (cusecs)	0.310	0.315
Range in ft. with ± 3 per cent. variation in Q	0.60	0.48

Actually, however, the module which was wider in experiment 8 gave a smaller range. In fact, there is an optimum B/D. As a rough guide to estimate friction losses, the Lacey and Manning formula were used.

According to Lacey's formula, the loss of head due to friction

$$h_f \propto \frac{L \bar{V}^2}{R^{1.5}}$$

$$\propto \frac{L D}{R^{1.5}}$$

where L=length of eddy chamber measured along the centre line

$$= \pi \left(\frac{r_o + r_i}{2} \right)$$

\bar{V} =mean velocity of flow in eddy chamber

D=Total energy

R=Hydraulic mean depth.

According to Manning

$$h_f \propto \frac{L D}{R^{1.33}}$$

14 NOTE ON THE THEORY, DESIGN AND CONSTRUCTION OF GIBB MODULES.

Table 12 and figure 12 show the effect of B/D or shape of the eddy chamber on calculated loss of head due to friction.

TABLE 12.—Showing friction loss estimated by Lacey and Manning formulas for various shapes of 1 cusec Gibb modules with $m=2.0$; $h_o/D=1/7$.

$$(Q=1.447 r_o D^{1.5}).$$

r_o (ft.).	D (ft.).	B (ft.).	B/D	L (ft.).	R (ft.).	h_f or units of friction $=LD/R^{1.48}$ (Lacey).	h_f $=LD/R^{1.49}$ (Manning).	REMARKS.
0.8	0.9067	0.40	0.441	1.8856	0.165	25.5	18.89	$h_1 = h_o \frac{r_o^3}{r_1^3} = 4 h_o$
1.2	0.6919	0.60	0.865	2.8254	0.199	21.8	16.84	
1.4	0.6244	0.70	1.120	3.2998	0.208	21.7	16.72	$d_1 = D - h_1 = 3 h_o$ as $D = 7 h_o$
1.6	0.5714	0.80	1.40	3.7712	0.213	21.85	16.94	Area = $B(D - h_o m)$ $= 5 B h_o$
2.0	0.4927	1.0	2.03	4.714	0.215	23.2	18.03	
2.5	0.4243	1.25	2.95	5.893	0.211	25.8	19.91	$d_o = 6 h_o$

$\therefore R = A/P = \frac{5 h_o B}{B + 9 h_o}$ and $L = 2.357 r_o$
 $P =$ wetted perimeter.
 $= B + d_o + d_1$
 $= B + 9 h_o$

FIG: 12 SHOWING FRICTION LOSS IN GIBB MODULES OF VARIOUS SHAPES. (B/D RATIOS)

$$m = 2.0 \text{ \& } \frac{h_o}{D} = \frac{1}{7}.$$

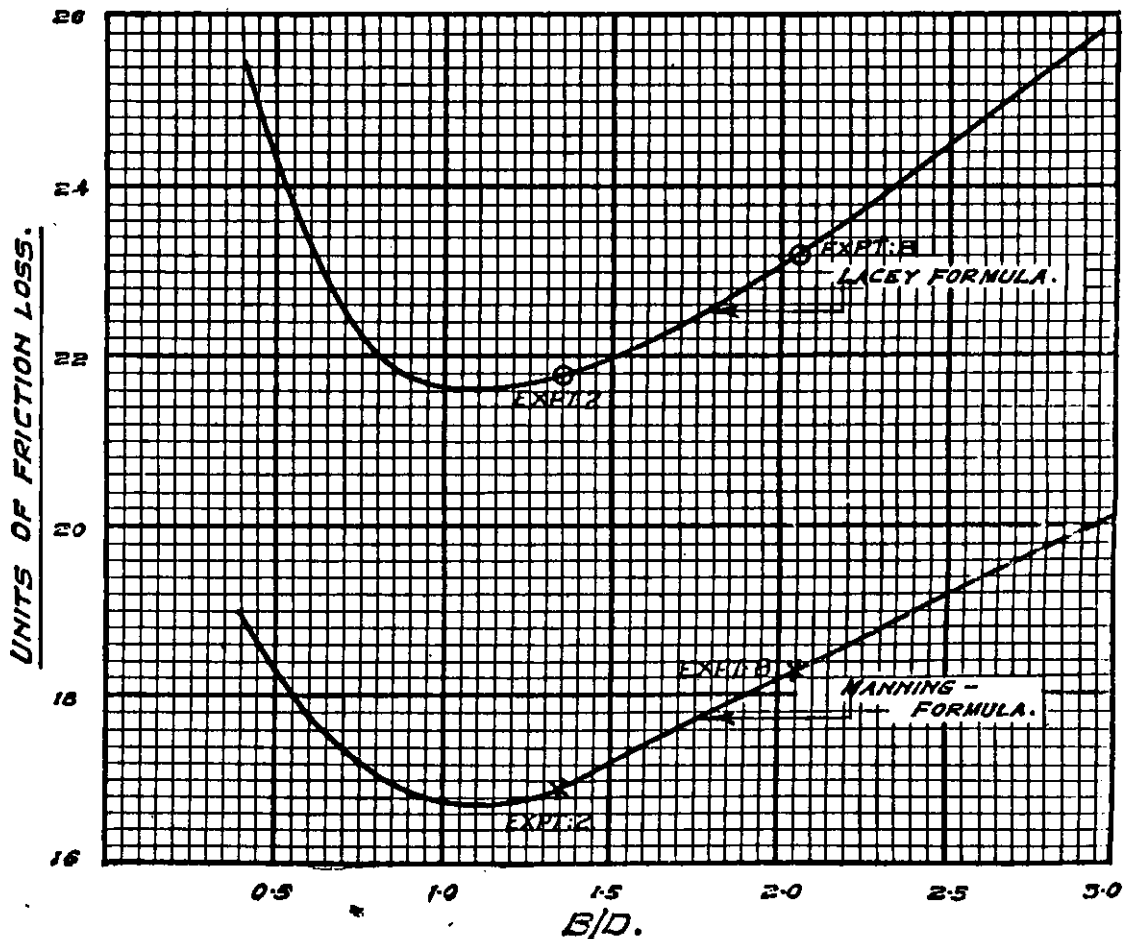


Figure 12 shows that the calculated loss of head due to friction increases in modules which are either too narrow or too broad, the loss being nearly the same for values of B/D lying between 0.8 and 1.5, m , h_0/D being 2.0 and 1/7 respectively.

In experiment 2—see table 11—, B/D was 1.36, *i.e.*, was within the above limit; whereas in experiment 8, B/D was 2.05, *i.e.*, outside the suitable range and the range was considerably less than in experiment 2. It appears that optimum results will be obtained with $m=2.0$; $h_0/D=1/7$ and B/D lying between 0.8 and 1.5.

15. EXPERIMENTS WITH MODULES OF 8 AND 16 CUSECS.

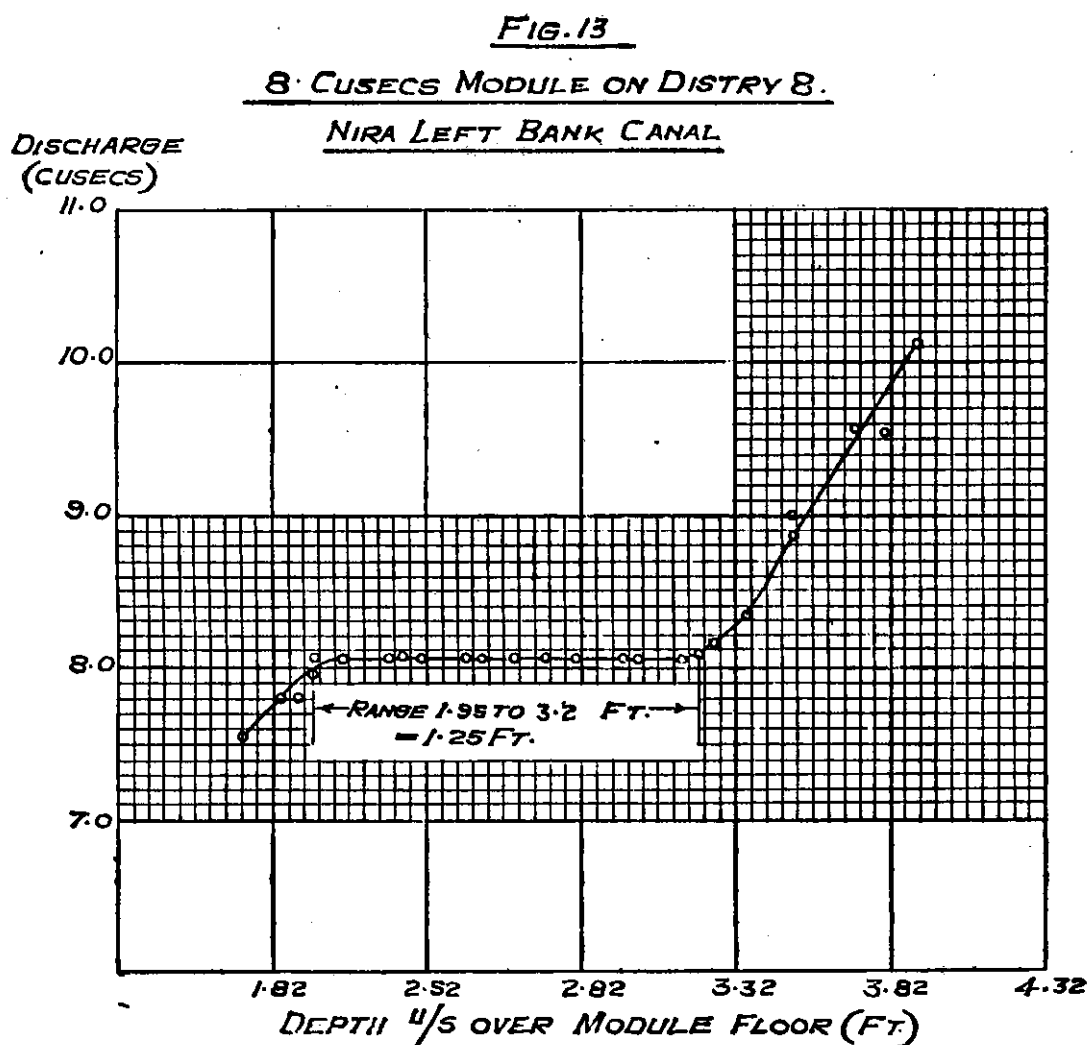
Two modules of 8 and 16 cusecs were constructed at the head of distributary 8 of the Nira Left Bank Canal—*vide* photo 1366.

Both modules flow during maximum demand, *i.e.*, in Kharif and Rabi seasons. In the Hot weather season, only one module is kept working, either 8 or 16 cusecs, depending on the demand.

In the case of 16 cusecs module, a stilling chamber was provided upstream of the module with an overflow pipe to indicate when the modular range is exceeded, so that the distributary Head Regulator gate can be lowered to increase loss of head from the canal and so decrease the level in the stilling chamber. In the case of 8 cusecs module, a stilling chamber was originally provided; it was not, however, constructed, but the inlet pipe of the module was directly joined to the distributary sluice.

Range.

Discharges were observed in the Standing Wave Flume already existing downstream of the modules. Figure 13 shows the discharge curve of 8 cusecs module.



8 cusecs module.

4 pressure pipes were fixed in the inlet pipe to record the upstream levels, to which the head due to velocity was added (*viz.*, 0.32 ft.). The range was found to be from 1.95 ft. to 3.2 ft., *i.e.*, only 1.25 ft.

16 cusecs module.

The range was from 2.4 ft. to 4.2 ft., *i.e.*, 1.8'. The range of 8 cusecs module was very low compared with the range of other modules tested as will be seen from figure 14 which shows the ranges of standard modules of various discharging capacities tested at Distributary 5, Mutha Right Bank Canal and Distributary 8, Nira Left Bank Canal (with $m=2.0$ and $h_0/D=1/7$). The discrepancy needs further verification, but is apparently due to unsatisfactory conditions arising from the module being added to an existing sluice.

Minimum working head.

TABLE 13.

	Minimum W. L. u/s over module floor.	Maximum W. L. downstream over module floor.	Minimum working head in ft., Col. 2—Col. 3.
1	2	3	4
8 cusecs module	1.95	1.08 or 0.69 D	0.87
16 cusecs module	2.4	1.25 or 0.71 D	1.15

The spout had 1 in 10 diverging flume downstream and hence the maximum permissible depth downstream was greater, *viz.*, 0.70 D against 0.61 D in modules without the diverging flume—*vide* para. 9.

16. SUMMARY OF RESULTS.

(1) Of the 6 baffles in the eddy chamber of the standard 3 cusecs module ($m=2.0$; $h_0/D=1/7$), the first 4 baffles were more effective in killing head, *viz.*, 1.12 ft. than 5 and 6 which increased the range by only 0.18 ft. and reduced the mean discharge from 3.20 cusecs to 3.10 cusecs.

(2) When a bellmouth was added to the inlet pipe, considerably less head was required to attain modularity and the range was increased.

(3) The range (*i.e.*, the range of upstream water levels over the module floor with ± 3 per cent. variation in Q) was maximum in Gibb's standard designs in which $m=2.0$ and $h_0/D=1/7$. According to Gibb, the range of a module can be increased by increasing the width of the eddy chamber, *i.e.*, by increasing B/D ratio; but this was not borne out by experiments and the values of B/D within which a high range is obtained is between 0.8 and 1.5.

(4) Increasing the number of baffles in a semi-circular module had no effect on range, though fluctuations of discharge within the range were reduced. The range was not increased by increasing the length of the arc of curvature through which water flows before entering the eddy chamber.

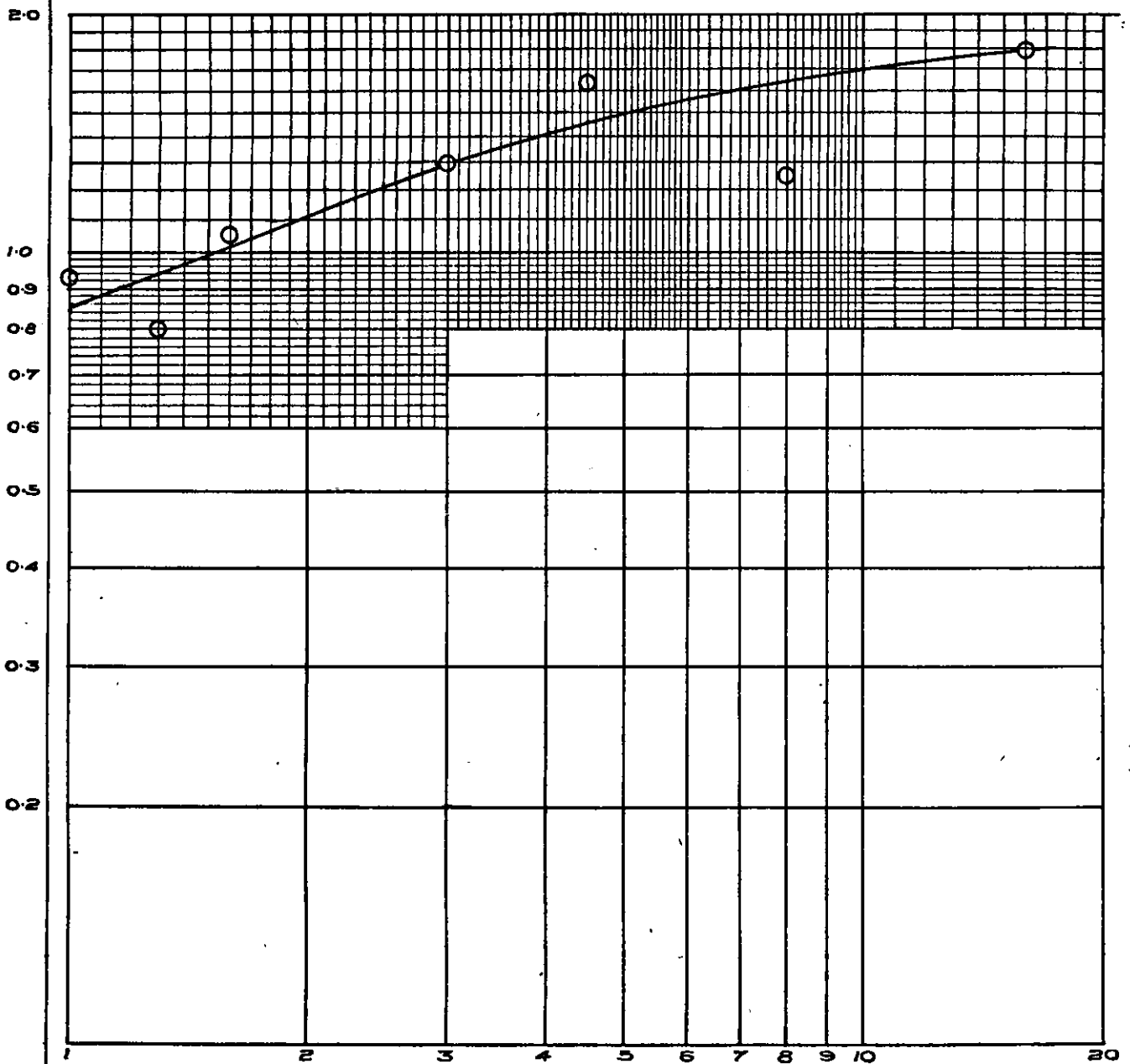
(5) According to Gibb, the range of a module can be increased by increasing the number of spirals of the eddy chamber; and he held that the range of a module with 3 semi-circles would be three times the range of a module of one semi-circle. This was not borne out by experiments: The range of one-cusec spiral module with 3 semi-circles was only 1.42 times that of "a single semi-circle" module.

(6) Maximum permissible downstream depth above the module floor was found to be 0.61 D against 0.56 D according to Gibb. With 1 in 10 diverging flume added to the spout, this was increased to 0.7 D. This modification is desirable.

(7) When the length of exit flume or spout=2 D, the range was a maximum.

FIGURE, - 14. SHOWING RANGE OF GIBB
MODULES TESTED AT D/5 - M.R.B.C.
AND D/8 - N.L.B.C.

RANGE IN FEET.



DISCHARGE IN CUSECS.

PART III.—STANDARD DESIGNS OF MODULES.

17. DESIGN OF THE INLET PIPE AND THE CURVED PIPE.

The area of the inlet pipe should be equal to the area of flow in the eddy chamber. The area of flow in the eddy chamber $= (r_o - r_i) (D - h_o m) = B (D - h_o m)$, see Appendix II. In the standard design, $h_o = D/7$ and $m = 2.0$

$$\therefore \frac{\pi d^2}{4} = B \left(D - \frac{D}{7} \times 2 \right) = 5/7 B D$$

$$\text{or diameter} = 0.95 \sqrt{B D}$$

The curved pipe is semi-circular in plan. The upstream end of the curved pipe takes off from the inlet pipe and the downstream end joins the eddy chamber, the cross section at the junction being as in figure 2 of Part II. The depth d at any point in the cross section can be worked out from the formula

$$\begin{aligned} d &= D - h \\ &= D - h_o \cdot \frac{r_o^2}{r^2} \end{aligned}$$

The circular section at the inlet end of the curved pipe is gradually developed to this section—*vide* Plates I and II.

18. SPACING OF BAFFLES IN EDDY CHAMBER.

The lower edges of all the baffles—which were called diaphragms by Gibb—should be at the same level. The lower edge of the baffles should meet the inner circumference at a height $= \frac{3}{4} d_o$ from the floor of the module and the outer circumference at d_o . Gibb laid it down that the number of baffles should be such that the distance between them measured along the outer circumference, should not be less than d_o nor greater than $2 d_o$. Our experiments have shown that within the above limits, increasing the number of baffles does not increase the range, but they tend to reduce fluctuations in the discharge.

19. LENGTH OF EXIT FLUME OR SPOUT.

Gibb stated in his Paper that the length of the spout— L —should be equal to the width of the eddy chamber; but L should be a function of D and not of B , and it has been standardised equal to $2 D$, for the same reason that Crump made his flume throat $= 2 D$, to eliminate draw-down and to ensure the control section being in the throat². When $L = 2D$, the range was a maximum. The recovery of head was greater when sides downstream of the spout splayed at 1 in 10—*vide* para. 15.

20. MINIMUM WORKING HEAD.

For a particular downstream water level in the distributary or water-course, the lowest level at which the module may be placed is fixed by the modular limit, and the minimum depth upstream over the sill is also fixed and the difference between the two is the minimum possible working head.

Our experiments have shown that the maximum depth of water permissible downstream over the module floor $= 0.64 D$ against $0.56 D$ according to Gibb. With a 1 in 10 diverging flume downstream of the spout, the maximum permissible depth downstream was found to be $0.70 D$.

21. MAXIMUM WORKING DEPTH.

The maximum working head $=$ the minimum working head *plus* the range.

If the head at F. S. L. in the parent channel exceeds the maximum working head, a regulating gate is necessary to keep the head within the modular range; and the gate should be so regulated as to keep the head within the modular range—allowing for fluctuations. The height of the eddy chamber $=$ the minimum working depth $+$ the range $+$ free-board of 6".

² P. W. D. Tech. Paper No. 15: "Notes on Standing Wave Flumes and Flume Meter Falls" by C. C. Inglis.

18 NOTE ON THE THEORY, DESIGN AND CONSTRUCTION OF GIBB MODULES.

22. STANDARD DESIGNS OF MODULES OF VARIOUS DISCHARGING CAPACITIES.

Table 14 shows the dimensions of inlet pipe and of modules of 1, 2, 3, 4, 5, 8, 10 and 16 cusecs and Plates I and II show the designs of 1 and 4 cusec modules and dimensions of the remaining modules. Item 2 of Table 14 shows the cost of modules of 1, 2 and 3 cusecs in reinforced cement concrete and of the remaining modules constructed in brick masonry. Generally modules of 1, 2 and 3 cusecs are required in large numbers and hence it is more economical to build these in sections in reinforced cement concrete. Plate III shows details of centerings of a 3 cusecs Gibb module in reinforced cement concrete.

TABLE 14.—Showing dimensions of Gibb Modules of 1, 2, 3, 4, 5, 8, 10 and 16 cusecs.

Item No. 1	Discharging capacity	1 cusec	2 cusecs	3 cusecs	4 cusecs	5 cusecs	8 cusecs	10 cusecs	16 cusecs
2	Cost of modules Re. . . .	90	115	190	320	340	500	640	870
3	r_o (ft.)	1.5	1.916	2.75	2.58	2.75	3.25	3.664	5.0
4	r_1 (=B) (ft.)	0.75	0.958	1.375	1.29	1.375	1.625	1.832	2.5
5	$m=r_o/r_1$	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
6	D (ft.)	0.625	0.84	0.875	1.096	1.215	1.56	1.594	1.772
7	h_o (ft.)	0.089	0.12	0.125	0.156	0.174	0.22	0.228	0.253
8	d_o (ft.)	0.536	0.72	0.75	0.94	1.04	1.34	1.366	1.519
9	d_1 (ft.)	0.268	0.36	0.375	0.467	0.52	0.67	0.683	0.76
10	B/D	1.20	1.14	1.59	1.30	1.10	1.04	1.15	1.41
11	Diameter of inlet pipe . .	9"	10"	12"	15"	15"	18"	21"	24"
12	No. of baffles in eddy chamber.	5	5	6	7	7	7	8	10
13	Height of lower edge of baffle from module floor. } At outer circle.	0.536	0.72	0.75	0.94	1.04	1.34	1.366	1.519
14									
15	Minimum working depth upstream over module floor (ft.)	0.76	1.06	1.10	(1.25)	(1.43)	1.95	(2.20)	2.40
16	Minimum working head = Minimum W. L. upstream minus maximum W. L. downstream (ft.)	0.36	0.58	0.53	(0.59)	(0.69)	(1.00)	(1.23)	(1.32)
17	Minimum working head with 1 in 10 diverging flume downstream of spout.	(0.29)	(0.46)	(0.49)	(0.49)	(0.56)	0.87	(1.08)	1.15
18	Modular range with ± 3 per cent. variation in discharge (ft.)	0.93	(1.10)	1.30	(1.40)	(1.50)	(1.64)	(1.70)	1.80
19	Range stated by Gibb (ft.) .	0.70	1.20	1.50	1.40	1.60

REMARKS :—(1) Figures in brackets are either calculated or interpolated from the experimental results.
 (2) Figures for the minimum working depth upstream over the module floor in item 15 include losses in modules which take off from a chamber upstream, i.e., loss in bellmouth entrance, inlet and curved rising pipe. When modules take off directly from a Canal or Distributary, loss in outlet pipes will have to be added. This is explained in Part IV.

PART IV.—METHODS FOLLOWED DURING 1928-1931 IN REMODELLING AND MODULING DISTRIBUTARIES IN THE DECCAN, USING GIBB MODULES.

23. PREFACE.

In the Deccan, unlike in Northern India, the demand for irrigation water varies widely according to the crops grown, which in turn depends on the position relative to markets, the suitability of the soil for various types of crops with widely differing water requirements, and the financial standing and energy of the cultivators.

Distributaries had previously been designed without taking such variations into account and the discharges of outlets had been controlled almost entirely by gates, which were regulated by low-paid staff.

The Canal tracts have now been classified, taking into account these factors and it only remained to standardise the supply by the use of modules, which for Deccan conditions must give a known constant discharge.

24. DATA.

Before commencing remodelling, the following data were collected :—

- (1) Complete plans and sections of the whole distributary showing the position of existing outlets, their size, etc.
- (2) Soil classification plans for the distributary area.
- (3) Irrigable area after drainage, *i.e.*, the maximum that can possibly be developed.
- (4) The maximum areas previously under cultivation, showing the perennial block areas, 2-seasonal blocks or lease areas, and ordinary rabi areas.

25. SIZE OF OUTLETS.

A full supply coefficient of 50 was assumed for the outlet for cane, where the full supply coefficient is the number of acres irrigable per cusec capacity of a channel at its head,—that is to say one cusec of capacity will bring 50 acres of cane to maturity.

Similarly a capacity coefficient of 100 was assumed for other crops. So, knowing the proportion of perennial block area to the total irrigable area on any outlet, it was a simple piece of arithmetic to find out the size of the outlet module required. For example: If 1/9th the area was under cane and 8/9ths under other crops, or say 50 acres under cane requiring one cusec and 400 under other crops requiring 4 cusecs, then 5 cusecs would be required for 450 acres and 1 cusec per 90 acres. This was adopted as the maximum discharge coefficient; and held for well-drained areas where 33 per cent. of the area might be under sugarcane blocks; but where drainage was not so good, a lower figure was taken with a composite duty of 120; and for large tail outlets, where no cane was grown, as high as 150 was considered permissible.

A full supply coefficient of 90 assumed that practically the whole area is irrigated in well drained areas; where drainage was not so good some 30 per cent. was assumed to be unirrigated and in tail channels over 40 per cent.

Having found the *maximum size* of outlet required for maximum supply, the next point to decide was the *minimum supply* required. The minimum demand occurs at that period of the hot weather when only cane is being irrigated; and we assumed that 25 acres of cane could be irrigated per cusec of capacity of the module. That is to say it was assumed that the channels would be run for only 5 days in ten.

The above figures were adopted for capacity where the proportion of perennial block to the total irrigable area was not known and could not be predicted with accuracy; but where the concentration could be estimated from classification plans and the existing cane and other areas, the full supply coefficient was worked out as shown in the example.

The ultimate aim was to develop a definite ratio of perennial block area to other crop area for each outlet. This definite proportion could have been developed by imposing an irrigation cess.³

26. SIZE OF GIBB MODULES.

Modules were standardised in units of a *cusec*; and, when dividing by the full supply coefficient, the nearest whole figure was adopted. It was usually found, except on outlets which had a large area of cane in proportion to the rabi area, that the size of the module required for the hot weather was much smaller than required for the rabi season.

Two Gibb Modules were then fitted giving a total discharge equal to the rabi discharge, one of the modules giving the required hot weather discharge.

27. TAIL OUTLETS.

The tail outlets were ordinarily Standing Wave Flume meters sometimes with a discharge recorder.

The reason why semi-modules and not modules were used near the tail of a Distributary was because the tail outlets have to deal with whatever discharge is left over after the modules have taken their discharges.

For this reason tail outlets must be capable of passing considerable excesses without undue afflux.

Tail outlets being semi-modules or ordinary outlets, it was not necessary to find out the minimum discharges except to exclude those which would be non-economic.

The tail semi-module outlets were designed so that they could carry a discharge = \sqrt{Q} , where Q was the discharge of the distributary at its head. Thus, if the distributary discharge = 100 *cusecs*, semi-modular outlets were adopted to carry > 10 *cusecs*; while if distributary discharge = 9 *cusecs*, semi-modular outlets were adopted > 3 *cusecs*. This was to ensure that a very small discharge was not carried a long way in the distributary with correspondingly high losses.

28. MINOR DISTRIBUTARIES.

Where the size of an outlet worked out to more than 7 *cusecs* it was generally treated as a minor distributary, which had its own outlets and was designed similarly to the main distributary—but the tail portion of such a minor was generally not less than 4 *cusecs*.

29. LOSSES IN TRANSIT IN A DISTRIBUTARY.

Having found the sizes of the modules required for the maximum (or rabi) discharge and the minimum (or hot weather) discharge, the total outlet discharges required was added up and losses then taken into account.

It had been found that losses in a normal distributary⁴ were of the order of $0.16\sqrt{Q}$ *cusecs* per mile, where Q was the mean distributary discharge—hence the losses were approximately determined, and where higher losses were anticipated, a higher coefficient was adopted.

In a distributary, the velocity should not be less than V_c —Lacey's critical velocity, being equal to $1.15\sqrt{f_1R}$, f_1 being taken as equal to 0.8 for soil; and up to 2 V_c or even higher was allowed for murum sections. To prevent scour, berms were maintained—using 'mol' grass (*Pennisetum alopecuroides*) where scour was bad—. Dry stone pitching, which was found to encourage crabs and to be liable to collapse within a few years, was disallowed because it was found to do more harm than good; but in general such channels were regraded.

³ See page 3 of P. W. D. Tech. Paper No. 25: "Moduling operations on Distributary No. 8, Nira Left Bank Canal, and application of results to other Distributaries" by C. C. Inglis and D. V. Joglekar.

⁴ See page 10 of P. W. D. T. P. No. 19: "Note on design of Distributaries and their outlets in the Bombay Deccan" by C. C. Inglis.

30. REMODELLING AN EXISTING CHANNEL.

In remodelling a channel, the procedure was as follows :—

If the existing channel was working satisfactorily,

$$\frac{\text{New } Q_1}{\text{Present } Q} \propto (R_1/R)^{3/4} \times (S_1/S)^{1/2} \dots\dots \text{Lacey.}$$

Assuming $S_1=S$ (which is on the safe side), $Q_1/Q \propto (R_1/R)^{3/4}$

In other words, the best way to remodel an existing channel which works satisfactorily is to retain the shape and increase the size of the channel so as to give the right value of R ; but it is near enough to increase the area proportionally to the discharge.⁵

31. MODULES AT DISTRIBUTARY HEADS.

At distributary heads, the ideal aimed at was to have modules. As there is a considerable daily fluctuation in canal levels a Head Regulator module must have a considerable modular range. Data collected seemed to indicate that Gibb modules could be designed to give a 'range' of 2.8 ft. for a 25 cusecs module and 4.20 ft. for a 100 cusecs module and the range could be extended to any desired extent by killing excess head by gate regulation.

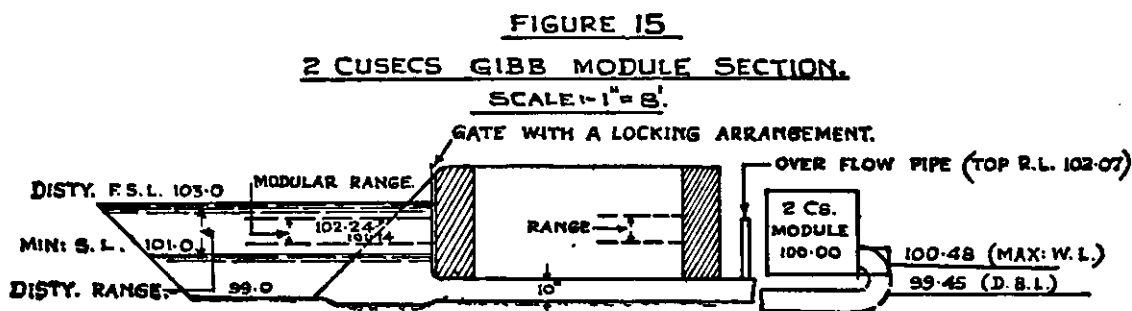
Two modules would be required for each Head Regulator—one for Hot weather conditions and the two combined for Rabi conditions. Two such modules of 8 cusecs and 16 cusecs were constructed at the head of Distributary 8, Nira Left Bank Canal.

Where standing wave flumes were in existence or were added, care was taken to see that the sill of the hump was sufficiently high for the flume not to be drowned at any discharge.

32. 'FIXING' AND 'SETTING' OF OUTLET MODULES.

For this, the range of the distributary water level at the outlet head must be known. Considering any outlet: the maximum distributary discharge at that outlet will be the distributary head discharge *minus* the summation of the maximum discharges of all other outlets upstream of this outlet, the outlet itself, and the losses between the head and the outlet.

Similarly the minimum distributary discharge at the outlet can be found. This determines the maximum and minimum discharges in the distributary at any outlet under normal conditions and from this the maximum and minimum water levels can be worked out. Figure 15 shows the conditions to be met for a 2-cusec Gibb Module fixed on a standard pipe outlet without any chamber.



NOTE.—The top of overflow pipe should be fixed allowing for entrance losses at the bell-mouth entrance of the pipe outlet and friction losses in the pipe. Thus R. L. of top of overflow pipe = $102.24 - 0.09 = 102.07$.

Tables 15 and 16 show heads required, range, etc., of 0.3, 1, 2 and 3 cusec modules.

⁵ See page 2 of P. W. D. Tech. Paper No. 42: "Notes on (1) Flumed aqueducts, (2) Remodelling an existing canal or distributary to pass an increased discharge, etc." by C. C. Inglis.

TABLE 15.—Showing the modular range, losses, etc., of Gibb Modules with a standard pipe outlet, (i) with a chamber at exit, (ii) without a chamber at exit.

q=discharge of the module.

	0.3 cusec	1.0 cusec	2.0 cusecs	3.0 cusecs
(1) Minimum W. L. upstream over module sill including losses				
(i) at the bell-mouth entrance of leading pipe	0.50	(0.76)	(1.06)	1.10
(ii) due to friction in the leading pipe 5 ft. long				
(iii) in the rising curved pipe (vide calculation sheet 1 in Appendix III)				
(2) Modular range	0.58'	0.93'	(1.10')	1.30'
(3) Maximum water level upstream over module sill (items 1 plus 2).	1.08'	(1.69)	(2.16)	2.40
(4) Maximum permissible depth in watercourse over module	0.22	0.40	(0.48)	0.57
I. With a chamber at exit of standard pipe outlet.				
Diameter of pipe	6"	9"	10"	12"
A=Area of pipe in sq. ft.	0.1964	0.4418	0.5410	0.7854
(5) (i) Loss of head in pipe outlet= $h = \frac{q^2}{52 A^2}$ where $c=0.9$ in $q=c A\sqrt{2gh}$	0.04'	0.10'	0.26'	0.28'
(ii) Loss in friction in the outlet pipe from $v=c/2\sqrt{dh/l}$ where $c=106$ d=diameter h=loss of head in ft. =length of pipe=15' say.	0.02	0.04	0.08	0.08
(iii) Loss of head in ft. in chamber at exit (See calculation sheet 2 in Appendix III).	0.02	0.04	0.13	0.13
Total loss=	0.08	0.18	0.47	0.49
(6) Minimum water level upstream in the distributary over module sill with the standard pipe outlet and a chamber (items 1 plus 5).	0.58	0.94	1.53	1.59
II. Without any chamber, i.e., the Gibb module is constructed in continuation of the pipe outlet.				
(7) (i) Loss at bell-mouth entrance of outlet already included in item 1 (i).				
(ii) Loss in friction in leading pipe say 20 ft. long. Loss in 5 ft. length of pipe already included in 1 (ii) ∴ Loss in 15 ft. length of pipe	0.02	0.04	0.08	0.08
(8) Minimum W. L. upstream in the distributary over module sill with the standard pipe outlet but with no chamber (items 1 plus 7).	0.52	0.80	1.14	1.18

Remarks :— $m = \frac{\text{outer radius } (r_o)}{\text{inner radius } (r_i)}$; Figures shown in brackets are calculated and not observed.
= 2 in all cases.

TABLE 16.—Showing the modular range, losses, etc., of Gibb Modules with a masonry outlet and a chamber at exit.

q=discharge of the module.

	0.3 cusec	1.0 cusec	2.0 cusecs	3.0 cusecs
(1) Minimum water level upstream over module sill Same as item (1) of Table 15.	0.50	(0.76)	(1.06)	1.10
(2) Modular range in ft.	0.58	0.93'	(1.10)	1.30
(3) Maximum W. L. upstream over module sill (items 1 plus 2) .	1.08	(1.69)	(2.16)	2.40
(4) Maximum permissible depth in watercourse over module sill .	0.22	0.40	(0.48)	0.57
(5) (i) Loss of head with a masonry outlet= $q^2/25 A^2$ where q=discharge; A=area; and c (in formula $q=c A\sqrt{2gh}$)=0.625				
Size of outlet channel	6"×6"	1'×9"	1'×1'	1'6"×1'
Loss of head	0.02'	0.07'	0.16'	0.24'
(ii) Loss in friction in outlet channel from $v = \frac{1.346}{N_s} R^{3/4} (h/1)^{1/2}$; l=15 ft. and $N_s=0.017$ for masonry in good condition (<i>vide</i> calculation sheet 3).	0.01'	0.03'	0.08'	0.06'
(iii) Loss in chamber at exit (<i>vide</i> calculation sheet 3 in Appendix III).	0.01'	0.01'	0.02'	0.02'
Total of item 5	0.04'	0.11'	0.26'	0.32'
(6) Minimum W. L. upstream over module sill with a masonry outlet and a chamber (items 1 plus 5).	0.54	0.87	1.32	1.42

Remarks :— $m = \frac{\text{outer radius } (r_o)}{\text{inner radius } (r_i)} = 2.0$ in all cases.

The module sill was fixed at such a level that the module would never be drowned by the downstream water level in the watercourse. That is to say it was fixed at the height shown in item (4) of Table 15 below the maximum watercourse level; if this meant placing the module undesirably high, it was necessary to exclude the high land, which normally was quite a small area of "not properly commanded" land, which had interfered to a very serious extent with distribution and had led to heavy percolation. The minimum difference of level permissible between the water level of the distributary and the module sill was that shown in item (8) for a standard pipe outlet without a chamber, or as shown in (6) if there was a chamber; or as shown in item 6 of Table 16 for a masonry outlet and a chamber.

Example.—The case shown in Figure 15 will be explained as an example for a 2 cusec module outlet; M. W. L. (maximum water level) was R. L. 100.48. Deducting 0.48 (*vide* item (4), Table 15) gave module sill level of 100.00.

Item (8) shows a minimum depth over sill of 1.14 required for a standard inlet pipe; so the minimum supply level in the distributary was 101.14 and maximum level in distributary was this figure plus the range (*see* item 2) or R. L. 102.24.

In this case the distributary range was greater than the modular range; the minimum water level being too low and the maximum water level too high.

There are two ways to neutralise excess head :—

- (i) raise the module sill or
- (ii) reduce the head by partially closing the outlet gate and preventing its being fully opened by having a locking arrangement on the outlet gate. This will kill the excess head.

(i) is better, where conditions permit, because it is fool-proof and tamper-proof; but (ii) will generally be better in the case of Distributary head modules or where subsequent scour may reduce the maximum water level.

In the example, the module sill could not be raised to R. L. 100.76, because the minimum water level in the distributary would then be 0.9 lower than required to give the designed discharge.

This could be set right either by a temporary stop gate or a weir designed to work with a small afflux at F. S. and with an afflux of not less than 0.9 ft. plus full supply afflux at minimum supply. If the F. S. afflux were say 0.4 ft., the minimum supply afflux must not be less than 1.3 ft.

Designs of Weirs or humps for this case are shown in Figures 16 and 17.

Figure 16 shows the S. W. F. type hump which is also a measuring device and Figure 17 shows a cheap type of hump.

Let F. S. Q. of the Distributary = 32 cusecs
 Minimum supply = 10.5 cusecs

FIG:16.
SECTION.
SCALE:- 5' = 1"

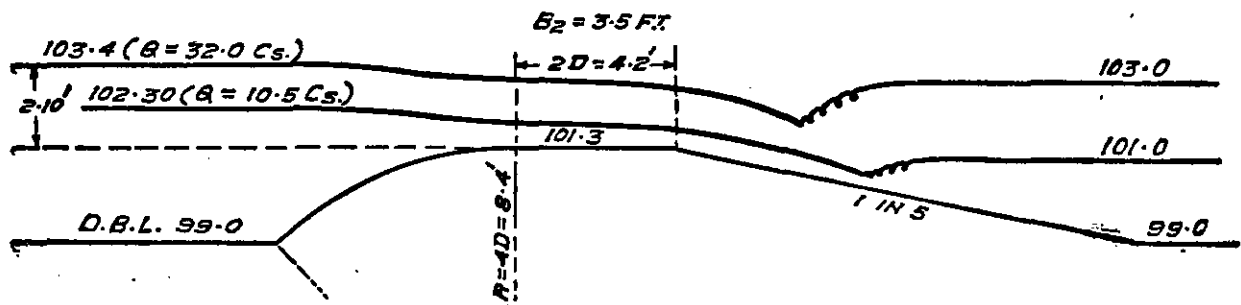


FIG:17.
SECTION.
SCALE:- 5' = 1"
B2 = 6 FT

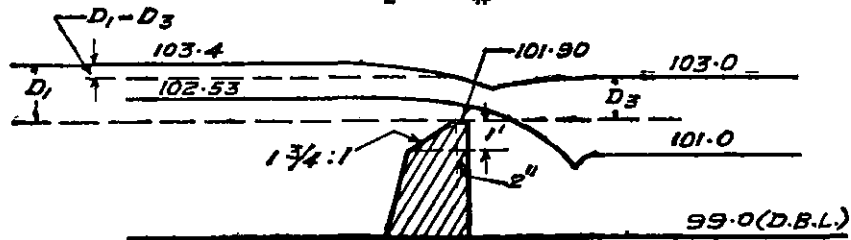


Figure 16 design.

F. S. L. in distributary downstream of hump = 103.0
 and F. S. D. = 4 ft.

allowing an afflux of 10 per cent., i.e., 0.4 ft., the upstream depth = 4.4 ft. and the upstream W. L. = 103.4 ft.

Let the throat width = 3.5 ft.

$$\therefore 3 \times B \times D^{1.6} = 32 \text{ cusecs or } D = 2.10 \text{ ft.}$$

The R. L. of hump will = 103.4 - 2.10 = 101.3; for Q = 10.5 cusecs, D = 1.0 and W. L. upstream of hump = 102.30. Allowing for an afflux of 0.4 at F. S. L., the module sill works out to R. L. 103.40 - 2.24 = R. L. 101.16 instead of R. L. 100.76 calculated above.

The afflux at minimum supply = 102.30 - 101.0
 = 1.30 ft.

and at full supply = 103.4 - 103.0
 = 0.4 ft.

Figure 17 design.

In this, the formulas for discharge were assumed as under :—

Case (i) The weir would be drowned under full supply conditions.

$$Q = 3.5 B (D_1 - D_3)^{1.5} + 6.4 B D_2 \sqrt{D_1 - D_3} \text{—see Fig. 17.}$$

Case (ii) There would be clear overfall with minimum supply level and $Q = 3.5 B D_1^{1.5}$.

Let R. L. of hump be 101.90 and the throat width = 6 ft. Assuming an afflux of 10 per cent. at full supply

$$\therefore \text{W. L. upstream at full supply} = 103.4$$

$$D_1 = 103.4 - 101.90 = 1.5 \text{ ft.}$$

$$\& D_3 = 103.0 - 101.90 = 1.1 \text{ ft. } \therefore D_1 - D_3 = 0.4 \text{ ft.}$$

$$\begin{aligned} \therefore Q &= 3.5 \times 6 \sqrt{0.4} + 6.4 \times 6 \times 1.1 \sqrt{0.4} \\ &= 32.06 \text{ which agrees with F. S. Q.} \end{aligned}$$

At minimum supply, $Q = 10.5 = 3.5 \times 6 \times D_1^{1.5}$

$\therefore D_1 = 0.63'$ and W. L. upstream of hump at minimum supply = 101.90 + 0.63 = R. L. 102.53 against 102.30 required.

When 2 Gibb modules of unequal size were fitted together on the same outlet either by using a Y piece or adding a chamber, the loss of head in the outlet was much greater when both modules were working than when only one was in use. As both modules are in use at times of full supply in the distributary, and only one module, as a rule, at times of low supply, this tends to increase the range; but as the range of the distributary when both modules are working is governed by the sill level of the smaller module; and if the minimum level in the distributary when both modules are working should fall below the modular limit of the smaller module, then no extension of range can be obtained by combining the 2 modules.

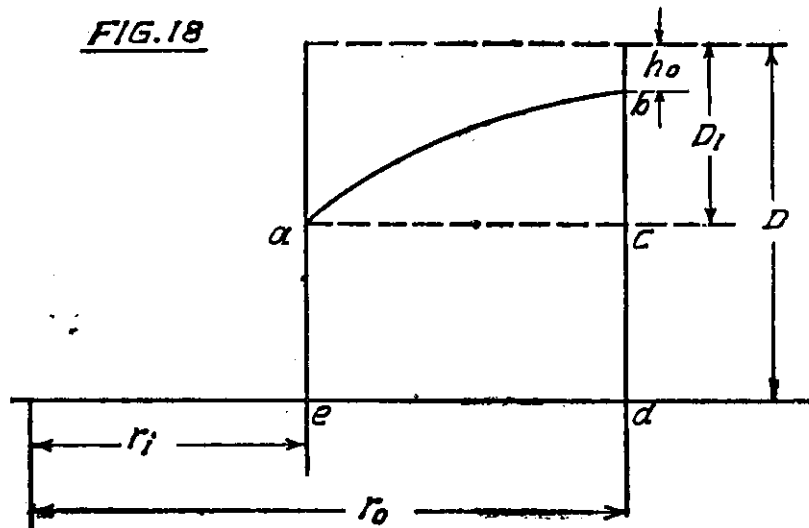
As already explained, where the range of the parent channel is great, the modules can be kept within their range by partially closing the gate. Such modules should have an overflow pipe downstream to show when the gate is insufficiently closed so that the head exceeds the modular limit of the module (*See Figure 15*).

Plate IV shows the type design then adopted for constructing a new outlet having one module.

Many people assisted in working out the system of remodelling adopted, especially Mr. J. S. Reid, Rao Sahib R. G. Islur, Rao Sahib N. S. Joshi and Mr. H. V. Katakhar.

APPENDIX I.

COMPARISON OF ORIGINAL GIBB FORMULA AND THE NEW GENERAL FORMULA.



Gibb's formula (with standard notation) for

$$q_{abc} = r_0 D_1^{3/2} \sqrt{2g} \left(\frac{1}{m} \log_e m - \frac{m^2 - 1}{2 m^3} \right) \quad (1)$$

General formula is :-

$$q_{abc} = \int_{r_1}^{r_0} \sqrt{2gh_0 \frac{r_0^2}{r^2} \left((D_1 - h_0) \frac{r_0^2}{r^2} \right)} dr$$

putting $h_0 = k D_1$

$$q_{abc} = r_0 \sqrt{2g} D_1^{3/2} \left[\sqrt{k} \log_e m + \frac{k^{3/2}}{2} (1 - m^2) \right] \quad (2)$$

∴ for the two formulae to agree

$$\sqrt{k} = \frac{1}{m} \text{ or } k = \frac{1}{m^2}$$

$$\text{and } \frac{k^{3/2} (1 - m^2)}{2} = \frac{1 - m^2}{2 m^3}$$

$$\text{or } k^{3/2} = \frac{1}{m^3} \text{ or } k = \frac{1}{m^2} \text{ i.e., } h_0 = \frac{D_1}{m^2}$$

For part a c d e, Gibb says

$$q_{acde} = r_0 \sqrt{2g} D_1^{3/2} \times \frac{m^2 - 1}{m^3} \log_e m \quad (3)$$

and the general formula gives

$$\begin{aligned} q_{acde} &= \int_{r_1}^{r_0} \sqrt{2gh_0} \frac{r_0^2}{r^2} dr = \sqrt{2gh_0} \int_{r_1}^{r_0} \frac{r_0^2}{r^2} dr \\ &= \sqrt{2gh_0} \int_{r_1}^{r_0} \frac{1}{r^2} dr \\ &= \sqrt{2gh_0} \left[-\frac{1}{r} \right]_{r_1}^{r_0} \\ &= \sqrt{2gh_0} \left(\frac{1}{r_1} - \frac{1}{r_0} \right) \\ &= \sqrt{2gh_0} \frac{r_0 - r_1}{r_1 r_0} \end{aligned} \quad (4)$$

For the two formulae 3 and 4 to agree,

$$D_1^{3/2} \times \frac{m^2 - 1}{m^3} = \sqrt{h_0} \frac{r_0 - r_1}{r_1 r_0}$$

but $h_0 = \frac{D_1}{m^2}$ as shown above

$$\therefore D_1^{3/2} \frac{(m^2 - 1)}{m^3} = \sqrt{\frac{D_1}{m}} \times \frac{r_0 - r_1}{r_1 r_0}$$

Gibb's results will agree with those for the general formula therefore, so long as

$$\begin{aligned}
 k &= \frac{1}{m^2} \text{ and } d_1 = \frac{D_1 (m^2 - 1)}{m^2} \text{ or } D = d_1 + D_1 \\
 &= \frac{h_o (m^2 - 1)}{k \frac{m^2}{m^2}} = D_1 \left(1 + \frac{m^2 - 1}{m^2} \right) \\
 &= h_o (2 m^2 - 1) \\
 \text{or } \frac{h_o}{D} &= K = \frac{1}{2m^2 - 1} \quad (5)
 \end{aligned}$$

This shows that Gibb's formula in terms of D_1 was not restricted to $m=2$, as he seems to have thought; but was nevertheless restricted to one shape.

COMPARISON OF NEW DESIGNS AND GIBB'S STANDARD DESIGN FOR A 3 CUSEC MODULE.

(a) Gibb's formulas are :-

$$Q = r_o \sqrt{2gh} H_1^{3/2} \left[\frac{1}{m} \log_e m - \frac{m^2 - 1}{2 m^3} + \frac{m^2 - 1}{m^3} \log_e m \right] \quad (6)$$

$$= r_o \sqrt{2g} H_1^{3/2} \left[\frac{2m^2 - 1}{m^3} \log_e m - \frac{m^2 - 1}{2 m^3} \right] \quad (7)$$

Gibb assumed that $H_1 = \frac{H}{2}$, where $H = D + h$ (i.e., head lost in inlet pipe).

$$\text{then } Q = \frac{r_o \sqrt{2g} H^{3/2}}{2\sqrt{2}} \left[\frac{2m^2 - 1}{m^3} \log_e m - \frac{m^2 - 1}{2 m^3} \right] \quad (8)$$

The general formula gives

$$Q = r_o \sqrt{2g} [D_1]^{3/2} \left\{ \sqrt{k} \log_e m + \frac{k^{3/2}}{2} (1 - m^2) \right\} + \sqrt{k} D_1 d_1 \log_e m \quad (9)$$

$$\begin{aligned}
 &= r_o \sqrt{2g} D_1^{1/2} \left[\sqrt{k} \log_e m (D_1 + d_1) + \frac{D_1 k^{3/2}}{2} (1 - m^2) \right] \\
 &= r_o \sqrt{2g} D_1^{1/2} \left[D \sqrt{k} \log_e m + \frac{D_1 k^{3/2}}{2} (1 - m^2) \right] \quad (10)
 \end{aligned}$$

Now $k D_1 = K D$

$$\text{or } D_1 = \frac{K}{k} D$$

$$\text{So } Q = r_o \sqrt{2g} D^{3/2} \left[\sqrt{K} \log_e m + \frac{K^{3/2}}{2} (1 - m^2) \right] \quad (11)$$

For the formulas 8 and 11 to agree,

$$\frac{H^{3/2}}{2\sqrt{2}} \left[\frac{2m^2 - 1}{m^3} \right] = D^{3/2} \sqrt{K}$$

$$\text{Now } K = \frac{1}{2m^2 - 1} = \frac{1}{7} \text{ when } m=2$$

$$\therefore \frac{H^{3/2}}{\sqrt{8}} \frac{7}{8} = D^{3/2} \times \frac{1}{\sqrt{7}}$$

$$\text{or } \frac{D}{H} = \frac{7\sqrt{7}}{8\sqrt{8}} \text{ or } \frac{D}{H} = \frac{7}{8}$$

The calculated discharge according to Gibb's formula for his three cusec standard design is equal to 3.21 cusecs, which shows that the actual discharge is 7 per cent less than the theoretical.

Q according to the general formula is

$$Q = r_o \sqrt{2g} D^{3/2} \left\{ \sqrt{K} \log_e m + \frac{K^{3/2}}{2} (1 - m^2) \right\}$$

28 NOTE ON THE THEORY, DESIGN AND CONSTRUCTION OF GIBB MODULES.

$r_0=2.75$ ft. ; $m=2$; $D=\frac{3}{8}$ when $H=1$; and

$$K = \frac{1}{2m^2 - 1} = \frac{1}{7}$$

$$\begin{aligned} \therefore Q &= 2.75 \times 8 \left\{ \frac{7\sqrt{7}}{8\sqrt{8}} \times \sqrt{\frac{1}{7}} \times 0.693 - \frac{3}{2} \times \frac{7\sqrt{7}}{8\sqrt{8}} \times \frac{1}{7\sqrt{7}} \right\} \\ &= 21.76 (0.2144 - 0.0663) \\ &= 3.22 \text{ cusecs.} \end{aligned}$$

Thus the two formulas agree, so long as

$$K = \frac{1}{2m^2 - 1}, \text{ etc.}$$

APPENDIX II.

AREA OF FLOW IN THE GENERAL FORMULA AND DIAMETER OF THE INLET PIPE.

$$\text{Area} = \int_{r_1}^{r_0} d \, dr; \text{ But } d = D - h_0 \frac{r_0^2}{r^2}$$

$$\begin{aligned} \therefore \text{Area} &= \int_{r_1}^{r_0} \left(D - h_0 \frac{r_0^2}{r^2} \right) dr \\ &= D (r_0 - r_1) - h_0 r_0^2 \left[\frac{1}{r_1} - \frac{1}{r_0} \right] \\ &= (r_0 - r_1) (D - h_0 m) \end{aligned}$$

$$\text{But } r_0 - r_1 = B \therefore \text{Area} = B (D - h_0 m)$$

Area of the inlet pipe should be equal to the area of flow in the eddy chamber, or $\pi \frac{d^2}{4} = B (D - h_0 m)$

$$\therefore d = \sqrt{\frac{4}{\pi} B (D - h_0 m)} = 1.13 \sqrt{B (D - h_0 m)}$$

d being diameter of pipe.

APPENDIX III.

CALCULATION SHEET OF TABLE 15.

Loss of head was calculated by observing pressure heads in the inlet and rising pipes of the standard 3 cusec module at D.5. They were found to be as under for the upstream depth = 1.0' over module sill at which the module began to work.

(i) Loss at bell-mouth entrance of inlet pipe	= 0.09'
(ii) Loss in inlet pipe 5 ft. long	= 0.03'
(iii) Loss in rising curved pipe	= 0.06'
	= 0.18'

As $h_o + d_o = 0.125 + 0.75 = 0.875'$

the actual loss of head = $1.10' - 0.875' = 0.225'$.

The difference between 0.225 and 0.18 = 0.045 is most probably due to a greater loss than observed in the rising pipe due to the changing section of the pipe and due to change of flow from parallel into free vortex. The loss in the rising curved pipe may therefore be taken = 0.11' against 0.06' observed. The total losses will then be

(i) 0.09'
(ii) 0.03'
(iii) 0.11'
0.23'

2. Loss of head in the case of 0.3, 1.0 and 2.0 cusec modules can be approximately found out as under :

(i) *Loss at Bell-mouth entrance of inlet pipe :*

$$v = c/2 \sqrt{\frac{dh}{l}} \text{ or loss } \propto \frac{v^2 l}{d}$$

As l is the same in all cases, loss $\propto v^2/d$

2 cusec module.

$$v = 3.7 \text{ f/s}; d = 0.83 \text{ ft. } \therefore v^2/d = 16.5$$

$$v^2/d \text{ for 3 cusec module} = \frac{(3.82)^2}{1.0} = 14.6$$

$$\therefore \text{loss at bell mouth entrance} = \frac{16.5}{14.6} \times 0.09' = 0.10'$$

Let it be the same as in 3 cusec module, i.e., 0.09'

1 cusec module.

$$v = 2.27 \text{ f/s}; d = 0.75' \quad v^2/d = 6.9$$

$$\therefore \text{loss} = \frac{6.9}{14.6} \times 0.09 = 0.04'$$

0.3 cusec module.

$$v = 1.53 \text{ f/s}; d = 0.5'; v^2/d = 4.7$$

$$\text{Loss} = \frac{4.7}{14.6} \times 0.09 = 0.03'$$

(ii) Loss in leading pipe 5 ft. long: $v = c/2 \sqrt{dh/l}$; $c = 106$.

By substituting values we get loss for 2 cusecs module = 0.03'

1 cusec module = 0.01'

0.3 cusecs module = 0.01'

(iii) Loss in the rising pipe can be approximately calculated on the assumption that loss

$$\propto \frac{v^2 l}{d}$$

1 i.e., the length of rising pipe of

3 cusec module=4.0'

2 cusec module=3.25'

1 cusec module=2.75'

0.3 cusec module=1.75'

Calculating in a similar way as in (i), we get for

3.0 cusec module, loss =0.06' observed

2.0 " " " =0.06'

1.0 " " " =0.02'

0.3 " " " =0.01'

As stated above, actual loss is greater and may be taken to be 0.11'; 0.09' and 0.09' respectively. Table 17 shows the calculated results.

TABLE 17.

	0.3 cusec module	1.0	2.0	3.0
$D=h_o+d_o$ (ft.)	0.37	0.62	0.84	0.87
Loss in bell-mouth entrance of leading pipe (ft.)	0.03	0.04	0.09	0.09
Loss in friction in leading pipe 5 ft. long (ft.)	0.01	0.01	0.03	0.03
Loss in rising pipe (ft.)	0.09	0.09	0.10	0.11
Total loss (ft.)	0.13	0.14	0.22	0.23
Minimum level u/s over module sill	0.50	0.76	1.06	1.10
These figures are shown in item 1 of Tables 15 and 16.				

CALCULATION SHEET 2 OF TABLE 15.

Loss of head in chamber at exit of the Standard Pipe outlet.

$$\text{Loss of head} = h = \left(\frac{v_2 - v_3}{2g} \right)^2$$

where v_2 is the velocity in the pipe outlet.

and v_3 is the velocity in chamber

3 cusec module.

$Q=3$ cusecs : diameter of pipe=12"

$\therefore v_2=3.85$ f/s

$v_3=0.91$ f/s, as width of chamber=5 ft.

and depth=1.10 ft.

$$\therefore h = \frac{(3.85 - 0.91)^2}{64} = 0.13 \text{ ft.}$$

2 cusec module.

$$v_2=3.70 \text{ f/s}; v_3 = \frac{2.0}{2.5 \times 1.06} = 0.75 \text{ f/s}$$

$$\therefore h = \frac{(3.70 - 0.75)^2}{2g} = 0.13'$$

1 cusec module.

$$v_2=2.27 \text{ f/s}; v_3 = \frac{1.0}{2 \times 0.76} = 0.66 \text{ f/s}$$

$$\therefore h = 0.04'$$

0.3 cusec module.

$$v_2 = 1.53 \text{ f/s and } v_3 = \frac{0.30}{2 \times 0.5} \text{ f/s}$$

$$h = \frac{(1.53 - 0.3)^2}{2g} = 0.02'$$

These figures are shown in item 5 (iii) of Table 15.

CALCULATION SHEET 3 OF TABLE 16.

Loss of head in outlet channel and chamber.

$$v = \frac{1.346}{N_s} R^{3/4} (h/l)^{1/2}$$

Where h = loss of head in friction

$N_s = 0.017$ for good masonry work

l = length of outlet channel = 15 ft.

3 cusec module.

Size of channel = 1.5' x 1'

$$V_2 = 2.0 = \frac{1.346}{0.017} \times (0.3)^{3/4} (h/15)^{1/2}$$

i.e., loss in outlet channel = 0.06 ft.

$$\begin{aligned} \text{loss in chamber} &= \frac{(v_2 - v_3)^2}{2g} \\ &= \frac{(2.0 - 0.91)^2}{2g} = 0.02' \end{aligned}$$

2 cusec module.

$v_2 = 2.0$ and $v_3 = 0.75$ f/s

loss in outlet channel = 0.08 ft.

loss in chamber = 0.02 ft.

Similarly in the case of 1 cusec and 0.3 cusec modules loss in outlet channel = 0.03' and 0.01' respectively and loss in chamber = 0.01' and 0.01' respectively.

These figures are shown in item 5 (ii) and (iii) of Table 16.

APPENDIX IV.

DESIGN OF ONE CUSEC SPIRAL GIBB MODULE.

1. The range of one cusec 'single semi-circle' module is 0.93'; and according to Gibb the range of spiral module of 3 semi-circles is 2.25 ft.

2. In the case of spiral modules, the water is led vertically upwards by a standard 90° bend connecting with the leading pipe. From this point, the water flows round in what is an upstream continuation of the module trough in which a series of guides (*vide* G in Plate V) are constructed to establish a free vortex flow.

3. In order to make an allowance for retardation in the spiral modules, Gibb assumed the following coefficients of discharge.

In the case of modules having two semi-circles

C for the 1st (upstream) semi-circle=0.85 and $m=r_0/r_1=2.0$

C for the 2nd (downstream) semi-circle=0.935 and $m=1.66$

In the case of modules having 3 semi-circles,

C for the 1st (upstream) semi-circle=0.758 and $m=2.0$

C for the 2nd (middle) semi-circle=0.85 and $m=1.66$

& C for the 3rd (downstream) semi-circle=0.935 and $m=1.5$

4. Let us first consider a spiral module of 3 semi-circles built of say 3/32" iron sheets.

1st (upstream) semi-circle.

Let $h_0 = 0.089'$ (*i.e.*, the same as in single semi-circle module)

$D=7 h_0=0.623'$ and $m=2.0$

$$Q=C \sqrt{2g} r_0 \left[D \sqrt{h_0} \log_e m - \frac{h_0^{1.5}}{2} (m^2 - 1) \right]$$

$$1.0=0.758 \times 8 \times r_0 \times (0.089)^{1.5} [7 \times 0.6931 - 1.5]$$

$$r_0 = 1.85 \text{ ft.}$$

$$r_1 = 0.92' \text{ and } B = \text{the width of eddy chamber} = 0.93'$$

2nd (middle) semi-circle.

$$r_0 = 2.5 \text{ } B = 2.32'$$

$$r_1 = 2.32 - B = 1.39' \text{ and } m = 1.66$$

$$1.0 = 0.85 \times 8 \times 2.32 \times h_0^{1.5} \left[7 \times \log_e 1.66 - \frac{m^2 - 1}{2} \right]$$

$$h_0 = 0.089' \text{ and } D = 7 h_0 = 0.623'$$

3rd (downstream) semi-circle.

$$r_0 = 3 \text{ } B = 2.79'$$

$$r_1 = 3 \text{ } B - B = 1.86'$$

and $m = 1.5$

$$1.0 = 0.935 \times 8 \times 2.79 \times h_0^{1.5} [7 \times 0.4055 - 0.625]$$

$$h_0 = 0.078' \text{ and } D = 7 h_0 = 0.546'$$

Diameter of the leading pipe

$$d = 1.13 \sqrt{B (D - h_0 m)}$$

$$= 1.13 \sqrt{0.93 (0.625 - 2 \times 0.089)}$$

$$= 0.73' \text{ or say } 9''$$

5. When considering the case of R. C. concrete modules, we have to increase r_0 and r_1 to make an allowance for the thickness of concrete walls.

Let the walls be 0.12' thick.

1st semi-circle.

Let $r_1 = 1.17'$ and $r_0 = 2.34'$; $m = 2.0$

$$1.0 = 0.758 \times 8 \times 2.94 \times h_0^{1.5} \left[7 \log_e 2 - \frac{m^2 - 1}{2} \right]$$

$$h_0 = 0.076'$$

2nd semi-circle.

$$2 r_1 = 2 B + 0.12 = 3.63'$$

$$\text{or } r_1 = 1.82'$$

$$2 r_o = 5 B + 0.12 \text{ and } r_o = 2.99$$

$$m = r_o / r_1 = 1.66$$

$$1.0 = 0.85 \times 8 \times 2.99 \times h_o^{1.5} [7 \times .5068 - 0.889]$$

$$h_o = .067 \text{ ft.}$$

3rd semi-circle.

$$2 r_1 = 4 B + 0.24$$

$$\text{or } r_1 = 2.46'$$

$$2 r_o = 6 B + 0.24$$

$$\text{or } r_o = 3.63'$$

$$m = 1.48$$

$$1.0 = 935 \times 8 \times 3.63 \times h_o^{1.5} \left[7 \times \log_e 1.48 - \frac{(1.48)^2 - 1}{2} \right]$$

$$h_o = 0.067'$$

Diameter of the leading pipe.

$$= 1.13 \sqrt{B (D - h_o m)}$$

$$= 1.13 \sqrt{1.17 (0.532 - 0.152)}$$

$$= 0.75'$$