STILLING BASIN FOR PIPE OR OPEN CHANNEL OUTLETS NO TAIL WATER REQUIRED (Basin VI in Frontispiece)

The stilling basin developed in these tests is an impact-type energy dissipator, contained in a relatively small boxlike structure, which requires no tail water for successful performance. Although the emphasis in this discussion is placed on use with pipe outlets, the entrance structure may be modified to use an open channel entrance.

Generalized design rules and procedures are presented to allow determining the proper basin size and all critical dimensions for a range of discharges up to 339 feet per second and velocities up to 30 feet per second.* Greater discharges may be handled by constructing multiple units side by side. The efficiency of the basin in accomplishing energy losses is greater than a hydraulic jump of the same Froude number.

The development of this short impact-type basin was initiated by the need for some 50 or more stilling structures on the Franklin Canal, Bostwick Division, Missouri River Basin Project. The need was for relatively small basins providing energy dissipation independent of a tail-water curve or tail water of any kind. The demand for information on general design procedures for use on other projects prompted the laboratory to include further investigation of this basin in the laboratory's general research program. Continued research on this type of basin will be made as time and funds permit.

Test Procedure

Hydraulic Models

Hydraulic models were used to develop the stilling basin, determine the discharge limitations, and obtain dimensions for the various parts of the basin. Basins 1.6 to 2.0 feet wide were used in the tests. The inlet pipe was 6-3/8 inches, inside diameter, and was equipped with a slide gate well upstream from the basin entrance, so that the desired relations between head, depth, and velocity could be obtained. The pipe was transparent so that backwater effects in the pipe could be studied. Discharges of over 3 cubic feet per second and velocities up to 15 feet per second could be obtained during the tests. Hydraulic model-prototype relations were used to scale up the results to predict performance for discharges up to 339 second-feet and velocities up to 30 feet per second.

The basin was tested in a tail box containing gravel, formed into a trapezoidal channel. The size of the gravel was changed several

*The laboratory has developed two basins for specific installations where velocities were considerably higher. One basin was for 10 second-feet at 80 feet per second, the other for 4 second-feet at 106 feet per second. Sufficient data are not available, however, to provide general design rules or procedures.

times during the tests. The outlet channel bottom was slightly wider than the basin and had 1:1 side slopes. A tail gate was provided at the downstream end to evaluate the effects of tail water.

Development of Basin

The finally evolved basin was the result of extensive tests on many different arrangements. A detailed discussion of these tests is not given, since they had little, if any, bearing on the final design, except in a general way. This is discussed below.

With the many combinations of discharge, velocity, and depth possible for the incoming flow, it became apparent during the early tests that some device was needed at the stilling basin entrance to convert the many possible flow patterns into a common pattern. The vertical hanging baffle proved to be this device, Figure 42. Regardless of the depth or velocity of the incoming flow (within the prescribed limits), the flow after striking the baffle acted the same as any other combination of depth and velocity. Thus, some of the variables were eliminated from the problem.

The effect of velocity alone was then investigated, and it was found that for velocities 30 feet per second and below (for a 42-inch pipe) the performance of the structure was primarily dependent on the discharge. Actually, the velocity of the incoming flow does effect the performance of the basin, but from a practical point of view, it could be eliminated from consideration. Had this not been done, considerably more testing would have been required to evaluate and express the effect of velocity.

For velocities of 30 feet per second or less, the basin width, W, was found to be a function of the discharge, with other basin dimensions being related to the width, Figure 42. To determine the necessary width, erosion test results, judgment, and operating experiences were all used, and the advice of laboratory and design personnel was used to obtain the finally determined limits. Since no definite line of demarcation between a "too wide" or "too narrow" basin exists, it was necessary to work between two more definite lines, shown on Figure 42 as the upper and lower limits. These lines required far less judgment to determine than a single intermediate line.

Various basin sizes, discharges, and velocities were tested, taking note of the erosion, wave heights, energy losses, and general performance. When the upper and lower limit lines had been established, a line about midway between the two was used to establish the proper width of basin for various discharges. The exact line is not shown because strict adherence to a single curve would result in difficult to use fractional dimensions. Accuracy of this degree is not justifiable. Figure 43 shows typical performance of the recommended stilling basin for the three limits discussed. It is evident that the center photograph represents a compromise between the upper limit operation, which is very mild, and the lower limit operation, which is approaching the unsafe range.

Using the middle range of basin widths, other basin dimensions were determined, modified, and made minimum by means of trial and error tests on the several models. Dimensions for nine different basins are shown in Table 11. These should not be arbitrarily reduced since in the interests of economy the dimensions have been reduced as far as is safely possible.

Performance of Basin

Energy dissipation is initiated by flow striking the vertical hanging baffle and being turned upstream by the horizontal portion of the baffle and by the floor, in vertical eddies. The structure, therefore, requires no tail water for energy dissipation as is necessary for a hydraulic jump basin. Tail-water as high as $d + \frac{g}{2}$, Figure 42, however, will improve the performance by reducing outlet velocities, providing a smooth water surface, and reducing tendencies toward erosion. Excessive tail water, on the other hand, will cause some flow to pass over the top of the baffle. This should be avoided if possible.

The effectiveness of the basin is best illustrated by comparing the energy losses within the structure to those which occur in a hydraulic jump. Based on depth and velocity measurements made in the approach pipe and in the downstream channel (no tail water), the change in momentum was computed as explained in Section 1 for the hydraulic jump. The Froude number of the incoming flow was computed using D_1, obtained by converting the flow area in the partly full pipe into an equivalent rectangle as wide as the pipe diameter. Compared to the losses in the hydraulic jump, Figure 44, the impact basin shows greater efficiency in performance. Inasmuch as the basin would have performed just as efficiently had the flow been introduced in a rectangular cross section, the above conclusion is valid.

Basin Design

Table 11 and the key drawing, Figure 42, may be used to obtain dimensions for the usual structure operating within usual ranges. However, a further understanding of the design limitations may help the designer to modify these dimensions when necessary for special operating conditions.

The basin dimensions, Columns 4 to 13, are a function of the maximum discharge to be expected, Column 3. Velocity at the stilling basin entrance need not be considered except that it should not exceed about 30 feet per second.

Table 11

STILLING BASIN DIMENSIONS
Impact-type Energy Dissipator
(Basin VI)

Suggested pipe size*		Maximum discharge	Feet and inches										Inches				
Dia in. (1)	Area (sq ft) (2)	Q (3)	W (4)	H (5)	L (6)	a (7)	b (8)	c (9)	d (10)	e (11)	f (12)	g (13)	t_w (14)	t_f (15)	t_b (16)	t_p (17)	K (18)
18	1.7672	21**	5-6	4-3	7-4	3-3	4-1	2-4	0-11	0-6	1-6	2-1	6	6-1/2	6	6	3
24	3.1416	38	6-9	5-3	9-0	3-11	5-1	2-10	1-2	0-6	2-0	2-6	6	6-1/2	6	6	3
30	4.9087	59	8-0	6-3	10-8	4-7	6-1	3-4	1-4	0-8	2-6	3-0	6	6-1/2	7	7	3
36	7.0686	85	9-3	7-3	12-4	5-3	7-1	3-10	1-7	0-8	3-0	3-6	7	7-1/2	8	8	3
42	9.6211	115	10-6	8-0	14-0	6-0	8-0	4-5	1-9	0-10	3-0	3-11	8	8-1/2	9	8	4
48	12.5664	151	11-9	9-0	15-8	6-9	8-11	4-11	2-0	0-10	3-0	4-5	9	9-1/2	10	8	4
54	15.9043	191	13-0	9-9	17-4	7-4	10-0	5-5	2-2	1-0	3-0	4-11	10	10-1/2	10	8	4
60	19.6350	236	14-3	10-9	19-0	8-0	11-0	5-11	2-5	1-0	3-0	5-4	11	11-1/2	11	8	6
72	28.2743	339	16-6	12-3	22-0	9-3	12-9	6-11	2-9	1-3	3-0	6-2	12	12-1/2	12	8	6

*Suggested pipe will run full when velocity is 12 feet per second or half full when velocity is 24 feet per second. Size may be modified for other velocities by Q = AV, but relation between Q and basin dimensions shown must be maintained.

**For discharges less than 21 second-feet, obtain basin width from curve of Figure 42. Other dimensions proportional to W; $H = \frac{3W}{4}$, $L = \frac{4W}{3}$, $d = \frac{W}{6}$, etc.

Columns 1 and 2 give the pipe sizes used in designs originating in the Commissioner's Office, Denver, Colorado. These may be changed as necessary, however. These suggested sizes were obtained by assuming the velocity of flow to be 12 feet per second. The pipes shown would then flow full at maximum discharge or they would flow half full at 24 feet per second. The basin operates as well whether a small pipe flowing full or a larger pipe flowing partially full is used. The pipe size may, therefore, be modified to fit existing conditions, but the relation between structure size and discharge should be maintained as given in the table. In fact, a pipe need not be used at all; an open channel having a width less than the basin width will perform equally as well.

The invert of the entrance pipe, or open channel, should be held at the elevation shown on the drawing of Figure 42, in line with the bottom of the baffle and the top of the end sill, regardless of the size of the pipe selected. The entrance pipe may be tilted downward somewhat without affecting performance adversely. A limit of 15^{o} is suggested maximum, although the loss in efficiency at 20^{o} may not cause excessive erosion. For greater slopes, use a horizontal or sloping pipe (up to 15^{o}) 2 or more diameters long just upstream from the stilling basin.

Under certain conditions of flow, a hydraulic jump may be expected to form in the downstream end of the pipe, sealing the exit end. If the upper end of the pipe is also sealed by incoming flow, a vent may be necessary to prevent pressure fluctuation in the system. A vent to the atmosphere, say one-sixth the pipe diameter, should be installed upstream from the jump.

The notches shown in the baffle are provided to aid in cleaning out the basin after prolonged nonuse of the structure. When the basin has silted level full of sediment before the start of the spill, the notches provide concentrated jets of water to clean the basin. The basin is designed, however, to carry the full discharge, shown in Table 11, over the top of the baffle if for any reason the space beneath the baffle becomes clogged, Figure 45C. Performance is not as good, naturally, but acceptable. With the basin operating normally, the notches provide some concentration of flow passing over the end sill, resulting in some tendency to scour, Figure 45A. Riprap as shown on the drawing will provide ample protection in the usual installation, but if the best possible performance is desired, it is recommended that the alternate and sill end 45^{o} end walls be used, Figure 45B. The extra sill length reduces flow concentration, scour tendencies, and the height of waves in the downstream channel.

Conclusions and Recommendations

The following procedures and rules pertain to the design of Basin VI:

1. Use of Basin VI is limited to cases where the velocity at the entrance to the stilling basin is about 30 feet per second or less.

2. From the maximum expected discharge, determine the stilling basin dimensions, using Table 11, Columns 3 to 13. The use of multiple units side by side may prove economical in some cases.

3. Compute the necessary pipe area from the velocity and discharge. The values in Table 11, Columns 1 and 2, are suggested sizes based on a velocity of 12 feet per second and the desire that the pipe run full at the discharge given in Column 3. Regardless of the pipe size chosen, maintain the relation between discharge and basin size given in the table. An open channel entrance may be used in place of a pipe. The approach channel should be narrower than the basin, with invert elevation the same as the pipe.

4. Although tail water is not necessary for successful operation, a moderate depth of tail water will improve the performance. For best performance, set the basin so that maximum tail water does not exceed $d + \frac{g}{2}$, Figure 42.

5. The thickness of various parts of the basin as used in the Commissioner's Office, Denver, Colorado, is given in Columns 14 to 18, Table 11.

6. The entrance pipe or channel may be tilted downward about 15^{o} without affecting performance adversely. For greater slopes use a horizontal or sloping pipe (up to 15^{o}) 2 or more diameters long just upstream from the stilling basin. Maintain proper elevation of invert at entrance as shown on the drawing.

7. If a hydraulic jump is expected to form in the downstream end of the pipe and the pipe entrance is sealed by incoming flow, install a vent about one-sixth the pipe diameter at any convenient location upstream from the jump.

8. For best possible operation of basin use the alternate end sill and 45^{o} wall design shown on Figure 42. Erosion tendencies will be reduced as shown on Figure 45.

*9. To prevent undermining of the end sill of the structure and erosion in the downstream channel, place riprap as shown on Figure 42. Suggested minimum sizes are as follows:

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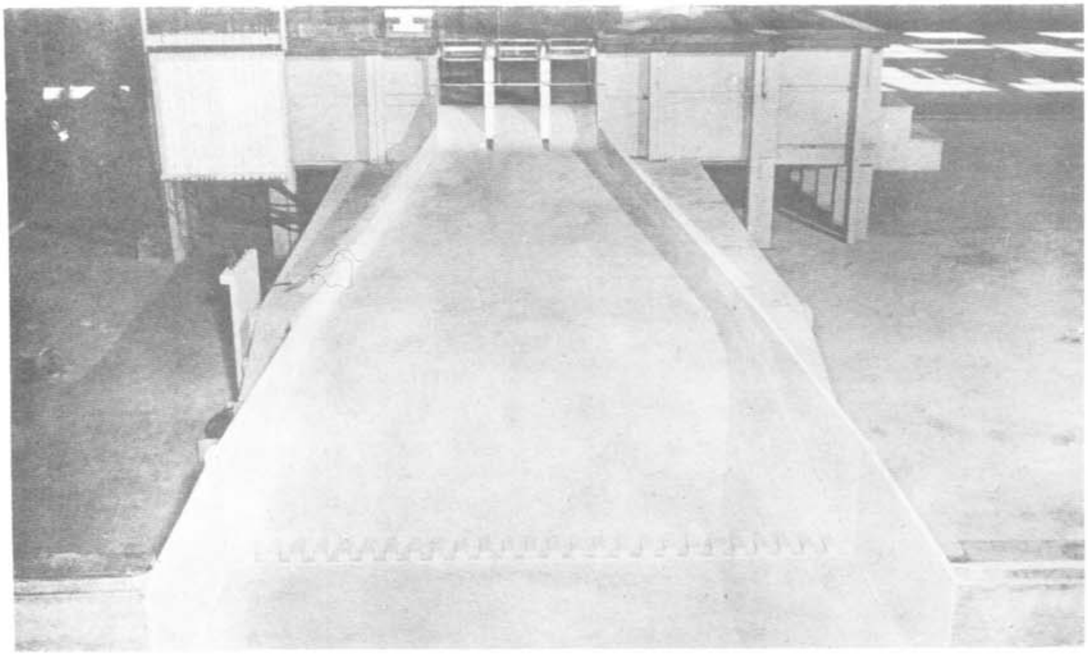
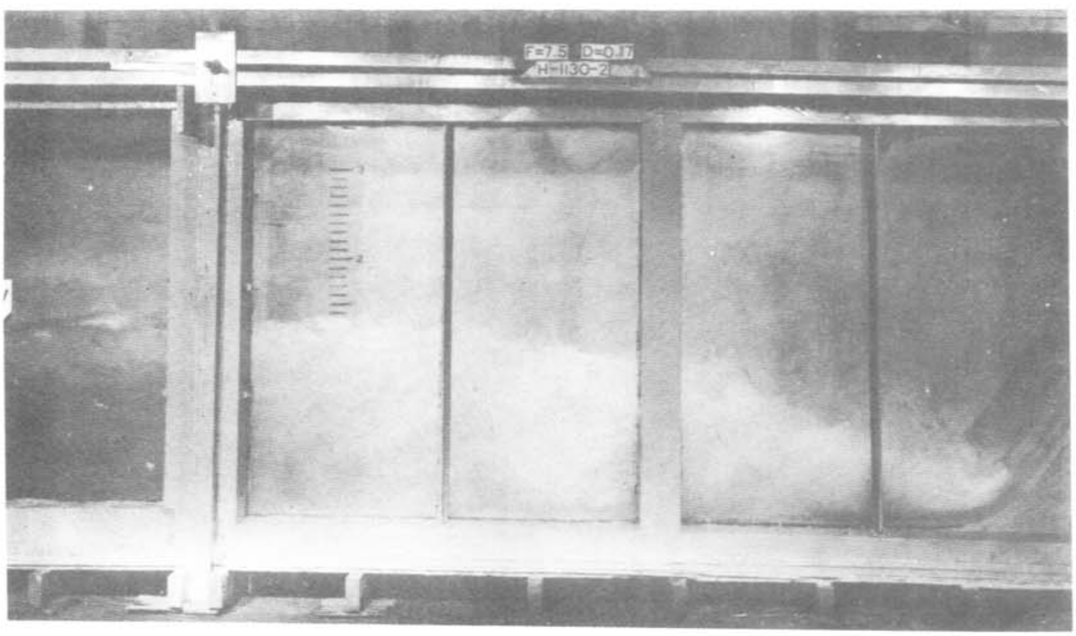
*The riprap sizes given have not been thoroughly tested and approved. At the present time this is the best information known, however, and it is believed to be on the conservative side. The Hydraulic Laboratory of the United States Bureau of Reclamation in Denver, Colorado, would welcome your comments based on experiences, data, photos, or other sources, either confirming or refuting the riprap sizes recommended.

Discharge (Col. 3 Table 11)	21	38	59	85	115	151	191	236	339
Nominal Rock Dia. (inches)	4.0	7.0	8.5	9.0	9.5	10.5	12.0	13.0	14.0

APPENDIX

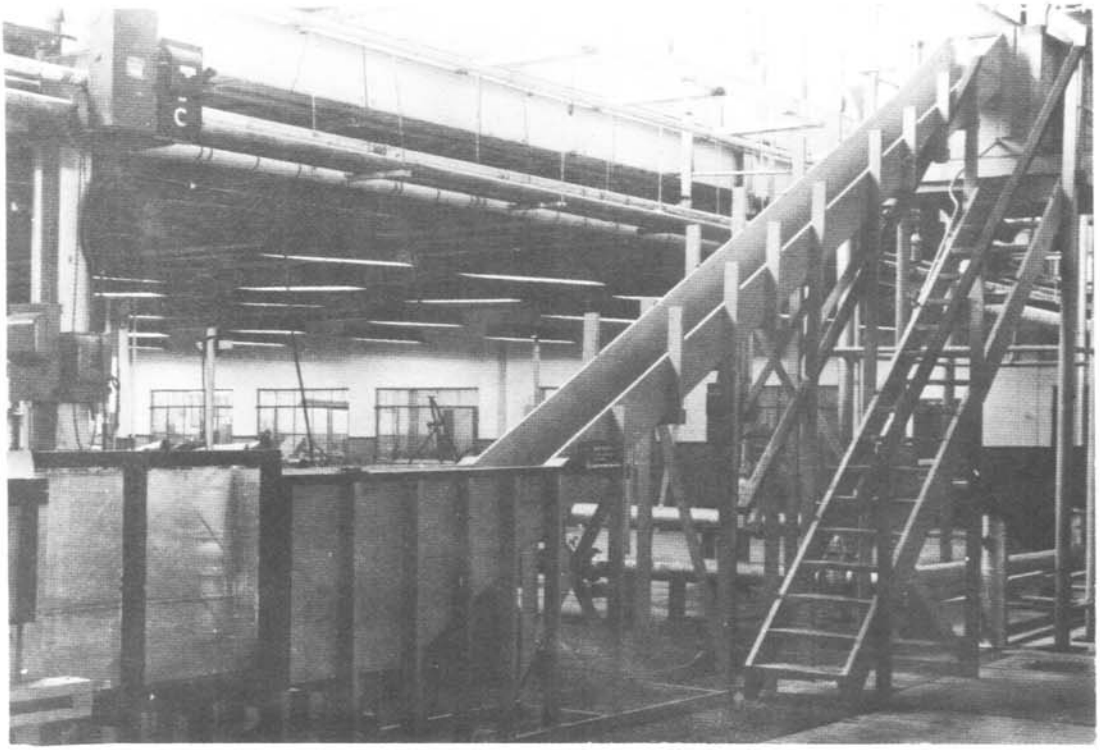


TEST FLUME A
Width of basin 5 feet, drop 3 feet, discharge 6 cfs

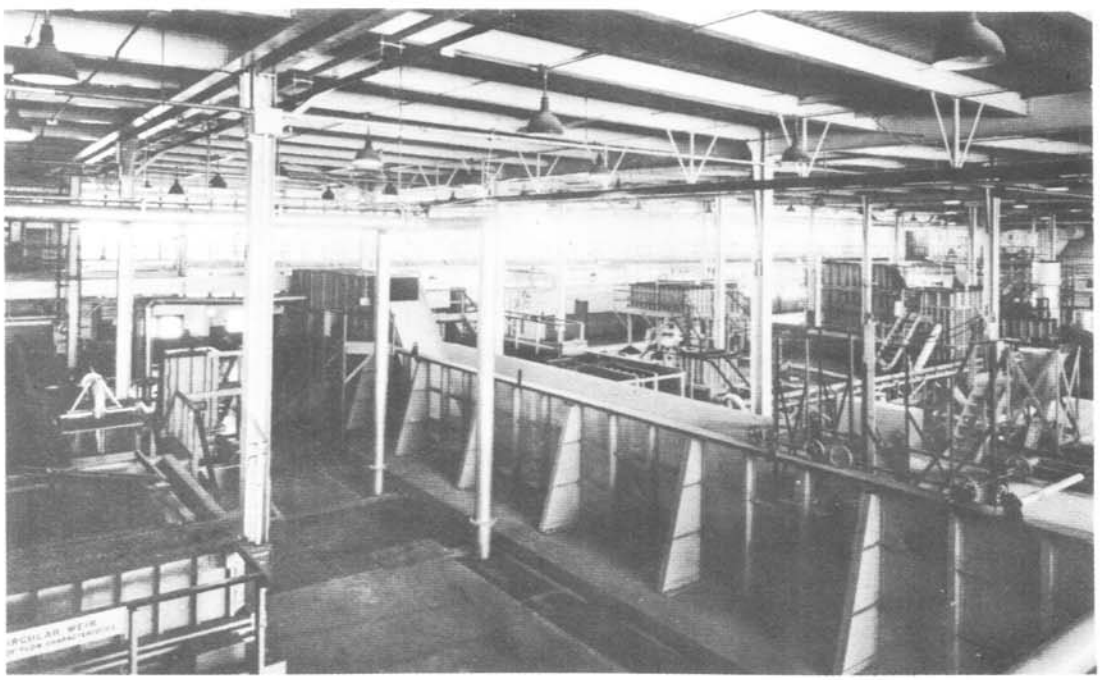


TEST FLUME B
Width 2 feet, drop 5.5 feet, discharge 10 cfs

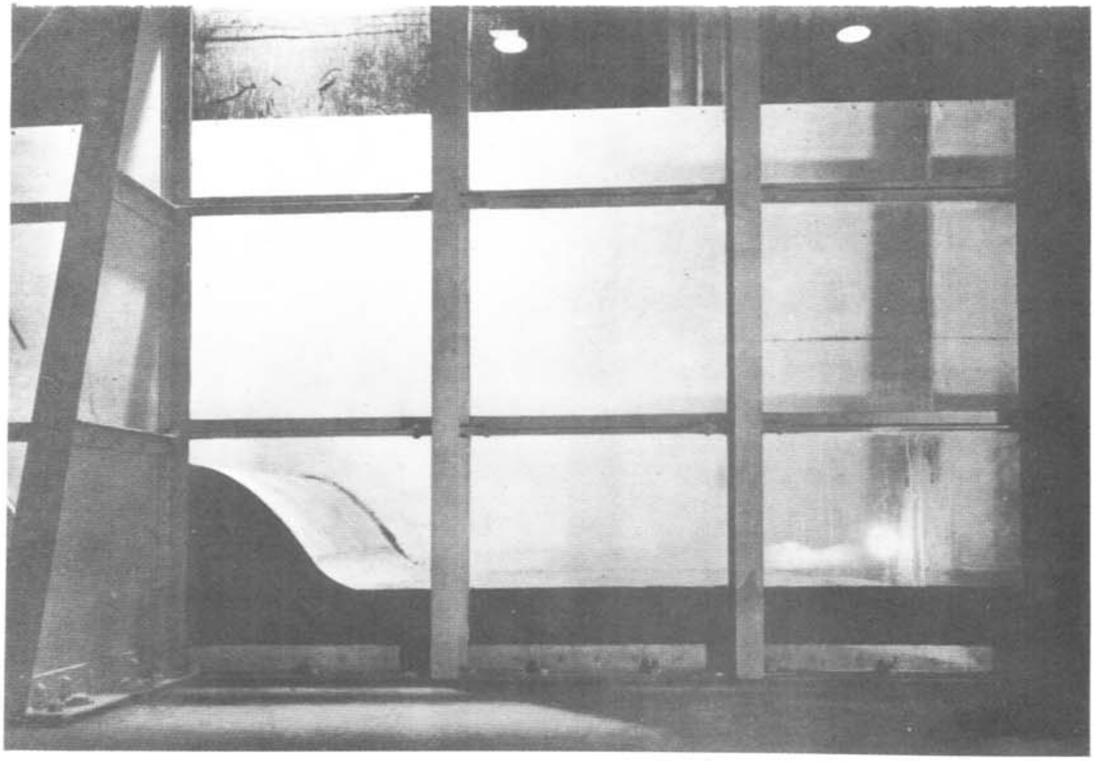
FIGURE 2



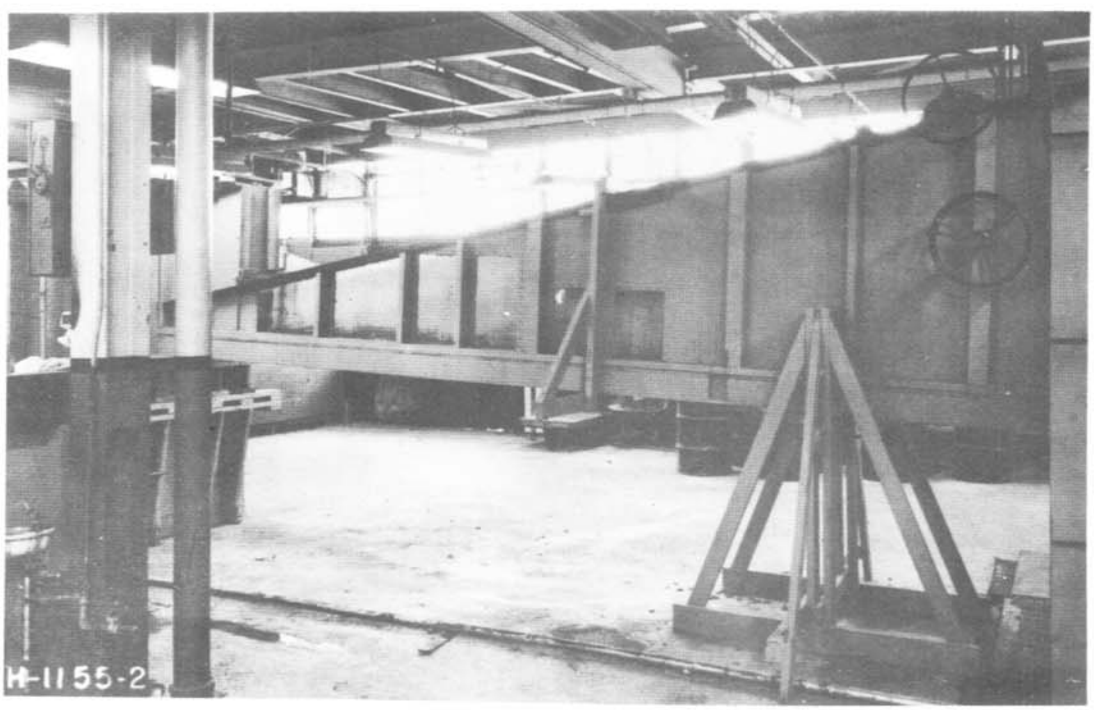
TEST FLUME C
Width 1.5 feet, drop 10 feet, discharge 5 cfs, slope 2:1



TEST FLUME D
Width 4 feet, drop 12 feet, discharge 28 cfs, slope 0.8:1

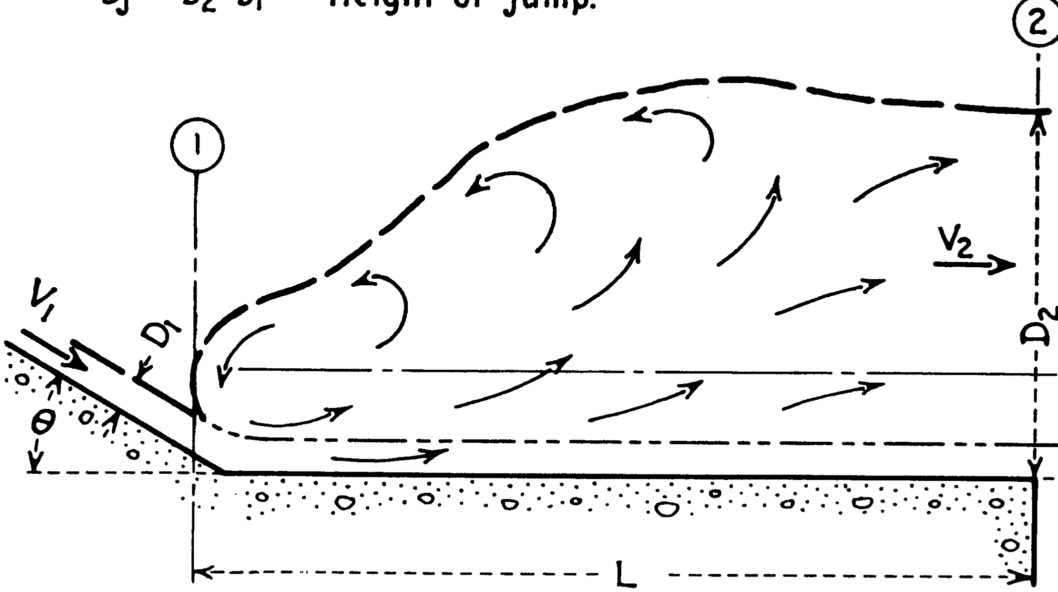


TEST FLUME (E)
Width 4 feet, Drop 0.5-1.5 feet, Discharge 10 cfs

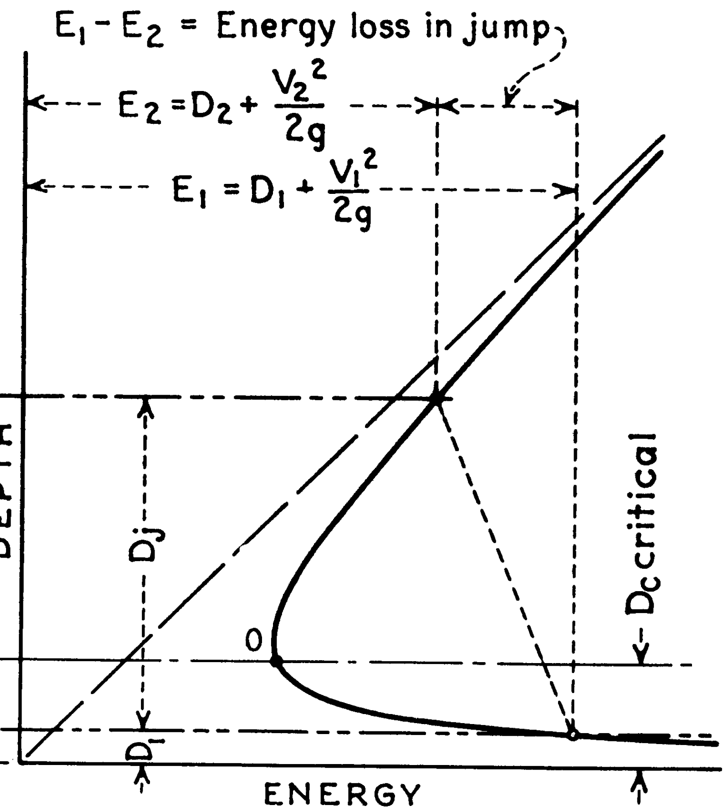


TEST FLUME (F)
Adjustable tilting type, maximum slope 12 degrees, width one foot, discharge 5 cfs

Q = Total discharge in c.f.s.
W = Width of flume in feet.
q = Discharge in c.f.s. per foot of width.
E_1 = Energy entering jump.
E_2 = Energy leaving jump.
F_1 = Froude number - $\frac{V_1}{\sqrt{g d_1}}$
D_j = $D_2 - D_1$ - Height of jump.



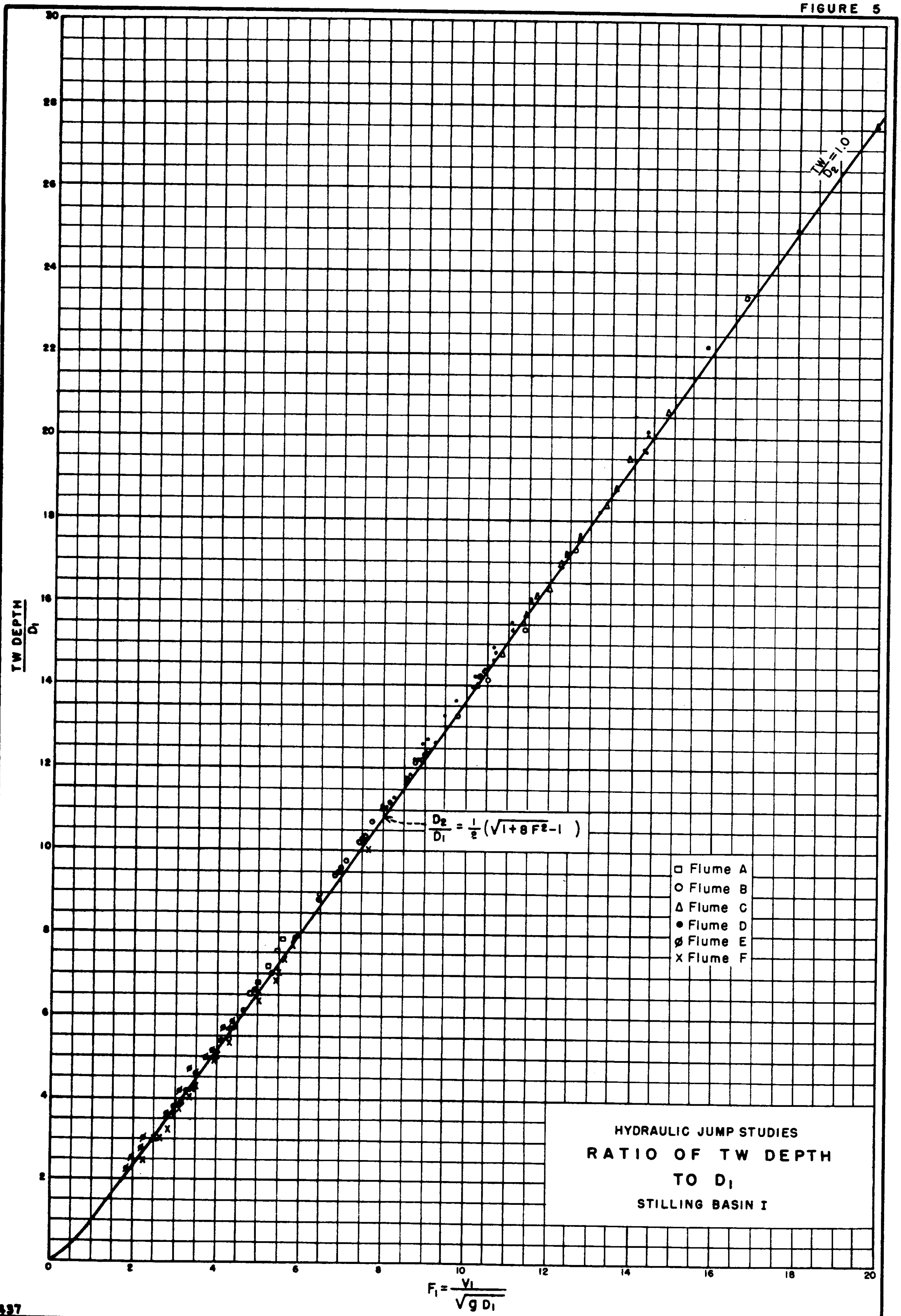
HYDRAULIC JUMP - ON HORIZONTAL FLOOR



RELATION OF SPECIFIC ENERGY TO DEPTH OF FLOW

HYDRAULIC JUMP STUDIES
STILLING BASIN I
DEFINITION OF SYMBOLS

437



HYDRAULIC JUMP STUDIES

RATIO OF TW DEPTH TO D_1

STILLING BASIN I

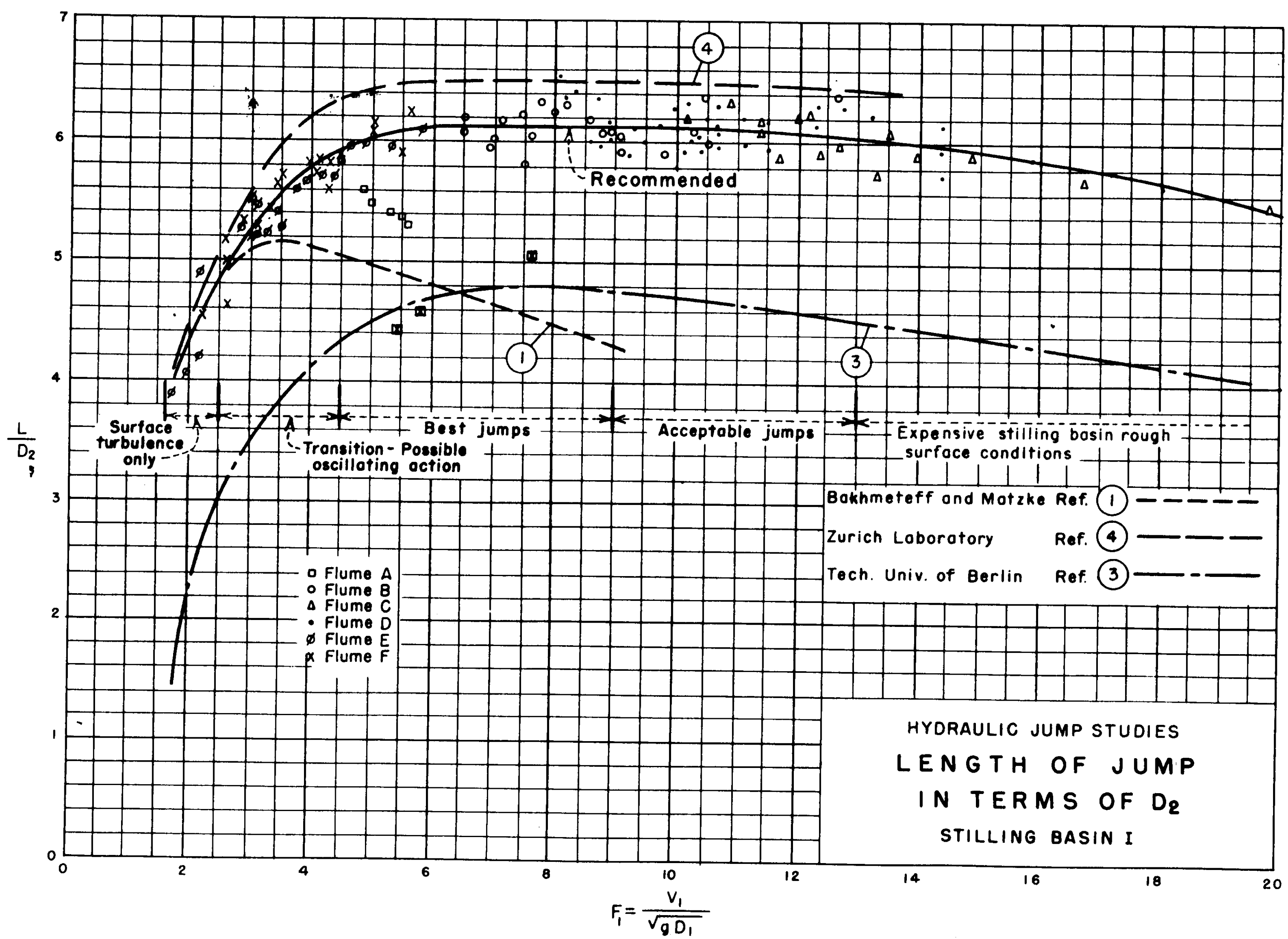
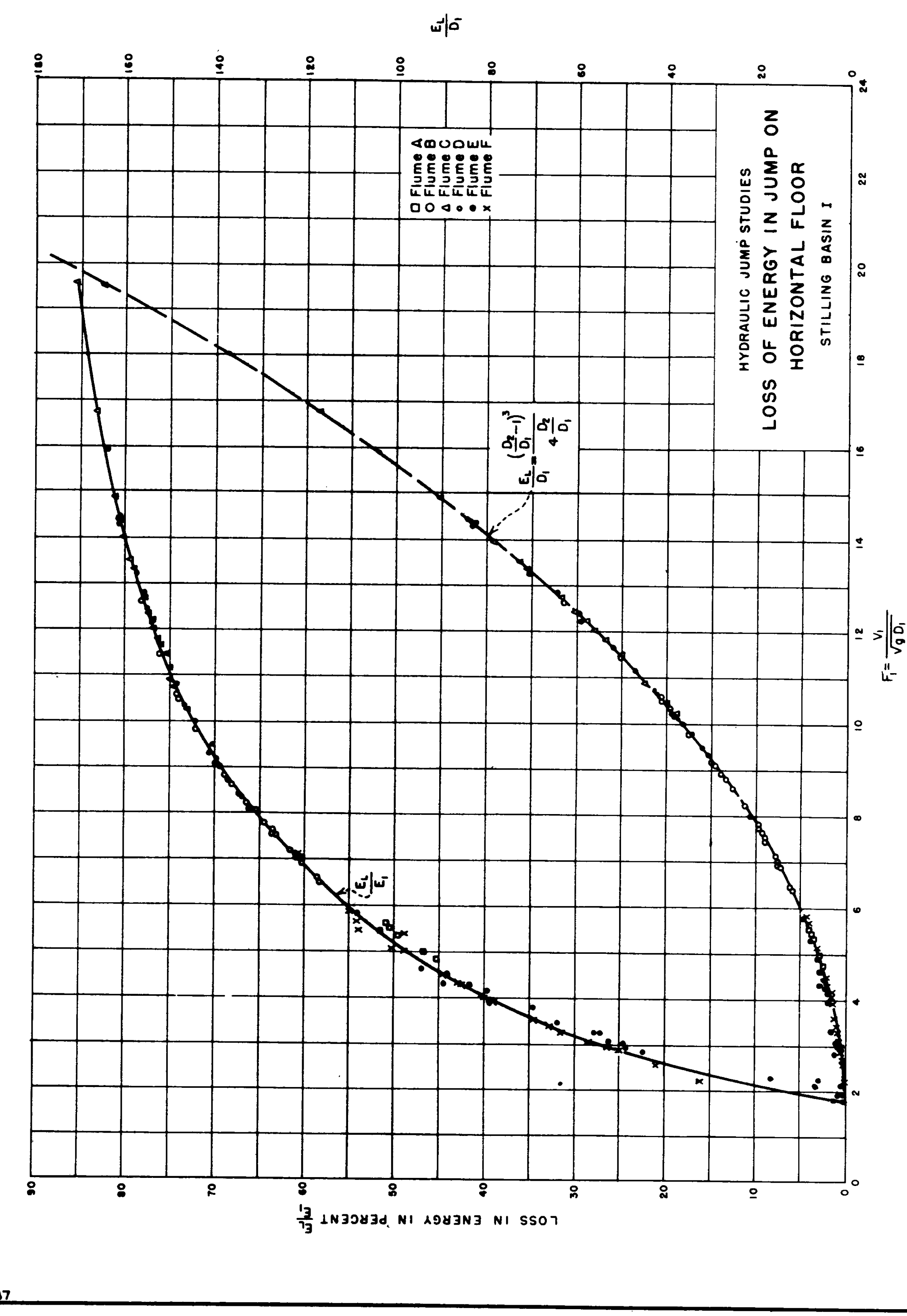
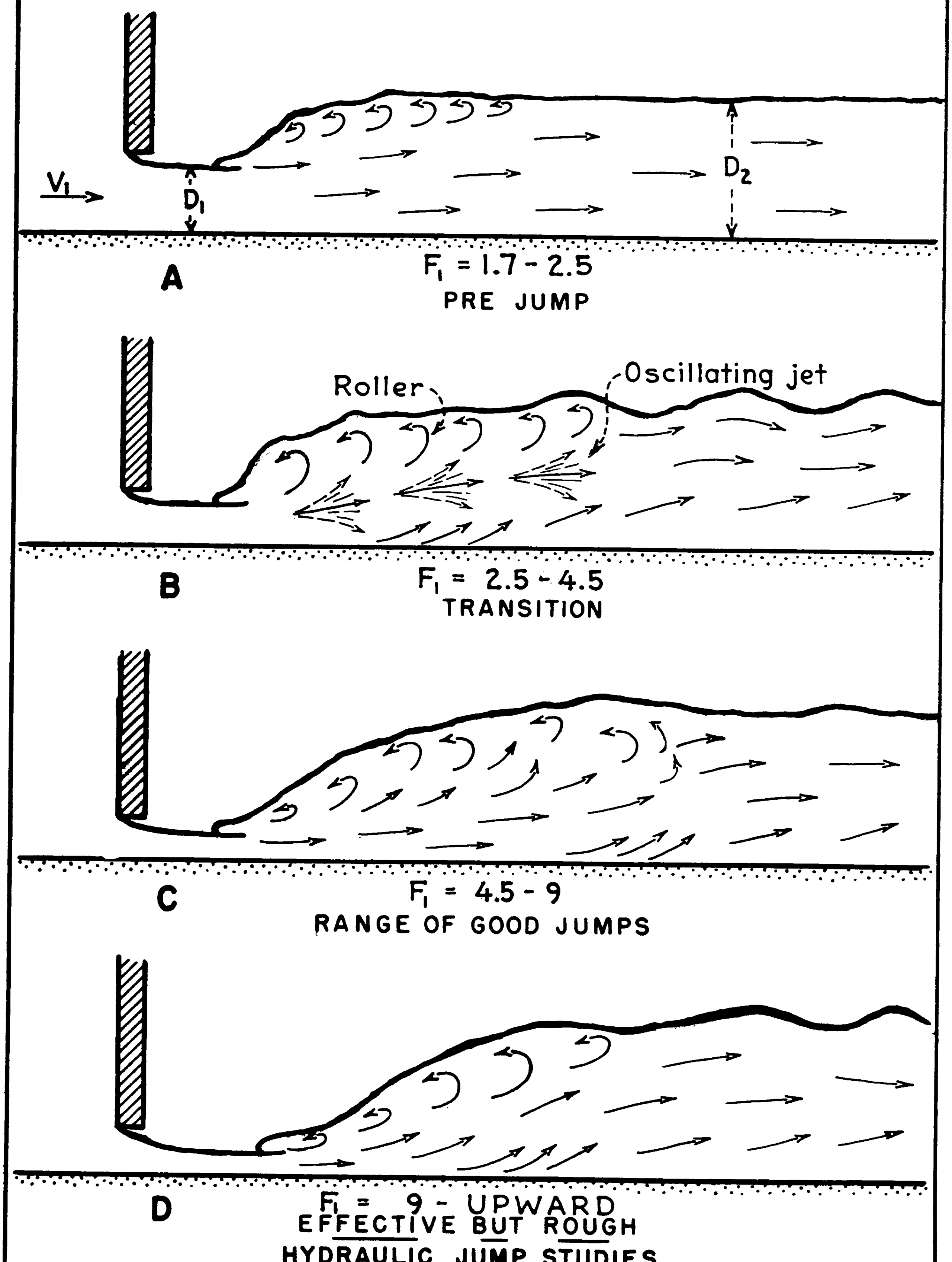

HYDRAULIC JUMP STUDIES
LENGTH OF JUMP
IN TERMS OF D2
STILLING BASIN I
L/D2
F1 = V1/√gD1
Surface turbulence only
Transition - Possible oscillating action
Best jumps
Acceptable jumps
Expensive stilling basin rough surface conditions
Recommended
Bakhmeteff and Matzke Ref. 1
Zurich Laboratory Ref. 4
Tech. Univ. of Berlin Ref. 3
Flume A
Flume B
Flume C
Flume D
Flume E
Flume F

FIGURE 7

FIGURE 8


HYDRAULIC JUMP STUDIES
LOSS OF ENERGY IN JUMP ON HORIZONTAL FLOOR
STILLING BASIN I
□ Flume A
○ Flume B
△ Flume C
∘ Flume D
• Flume E
x Flume F
$\frac{E_L}{D_1}$
$\frac{E_L}{D_1} = \frac{\left(\frac{D_2}{D_1}-1\right)^3}{4\frac{D_2}{D_1}}$
$\frac{E_L}{E_1}$
$F_1 = \frac{V_1}{\sqrt{gD_1}}$
LOSS IN ENERGY IN PERCENT $\frac{E_L}{E_1}$

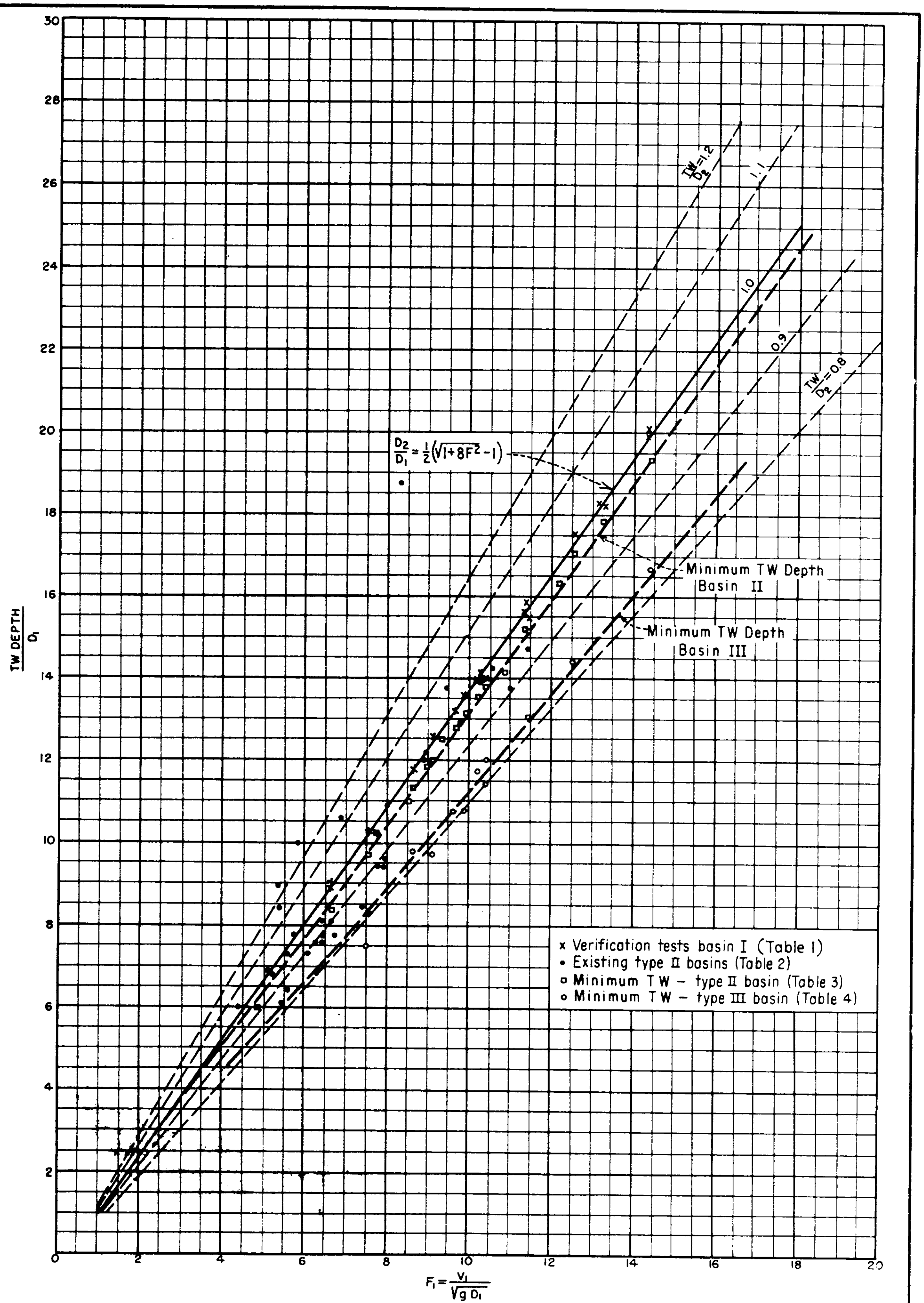


HYDRAULIC JUMP STUDIES

STILLING BASIN I

JUMP FORMS

437

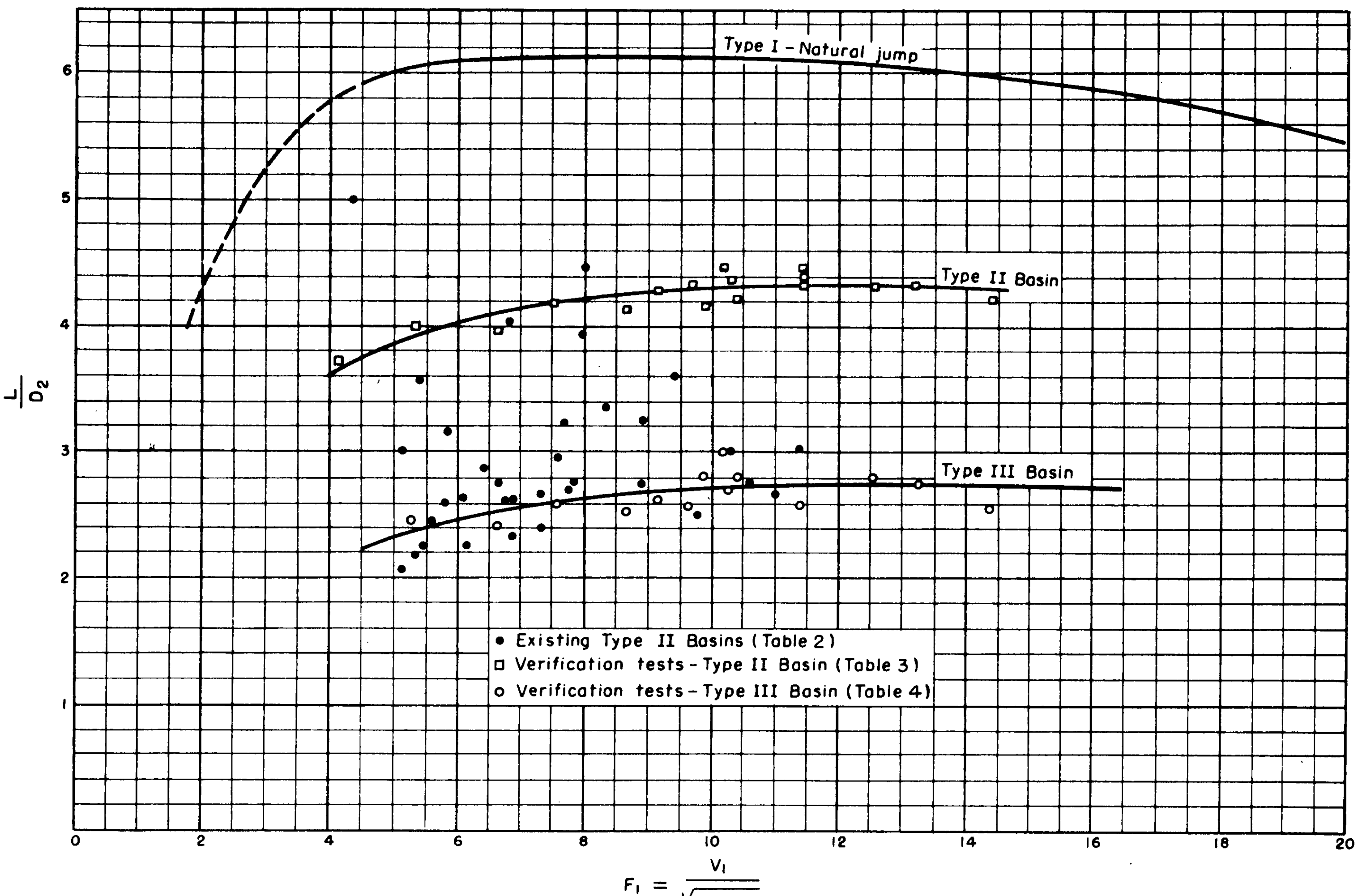


HYDRAULIC JUMP STUDIES

STILLING BASINS I, II AND III

MINIMUM TAILWATER DEPTHS

437

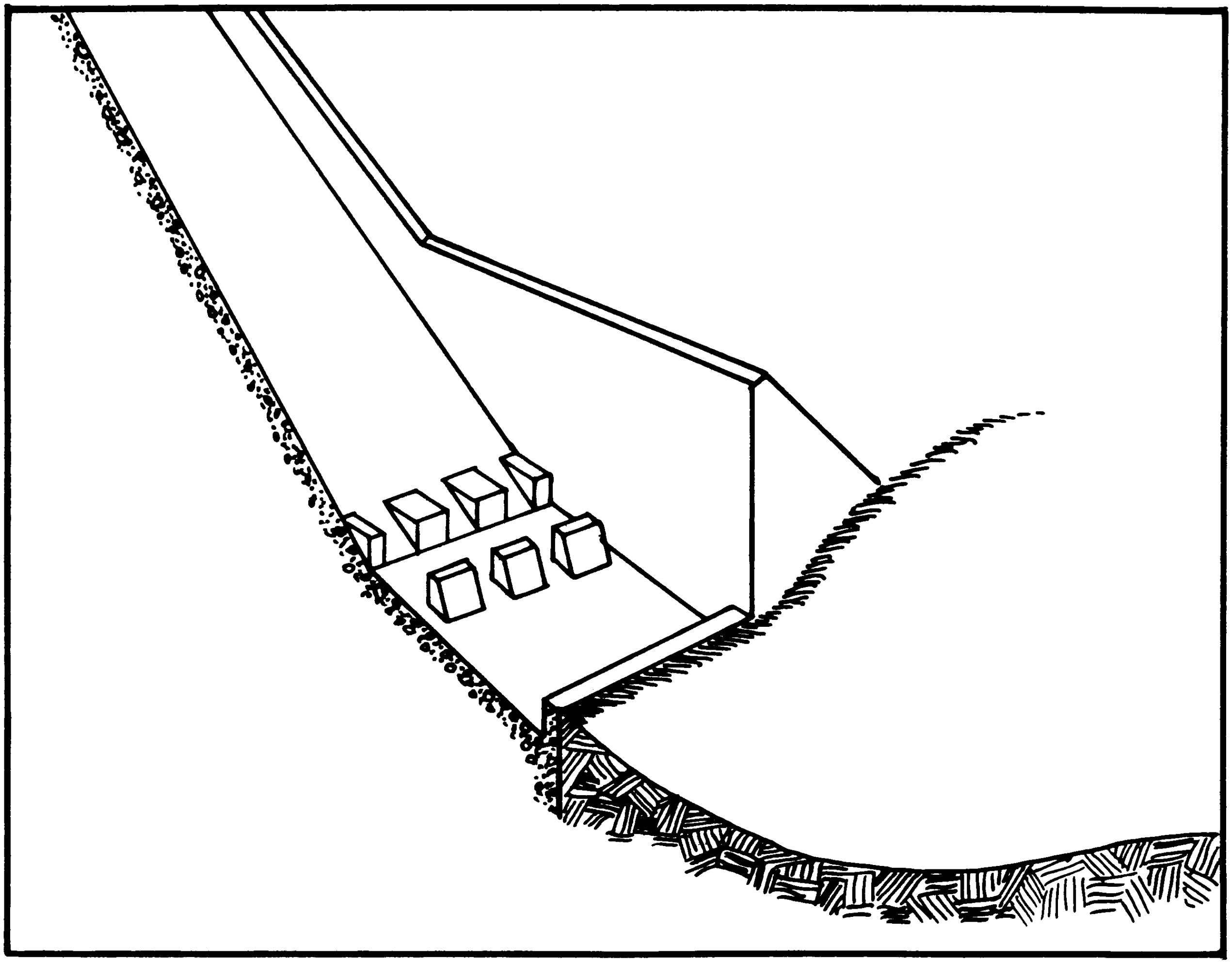


HYDRAULIC JUMP STUDIES

STILLING BASINS I, II, AND III

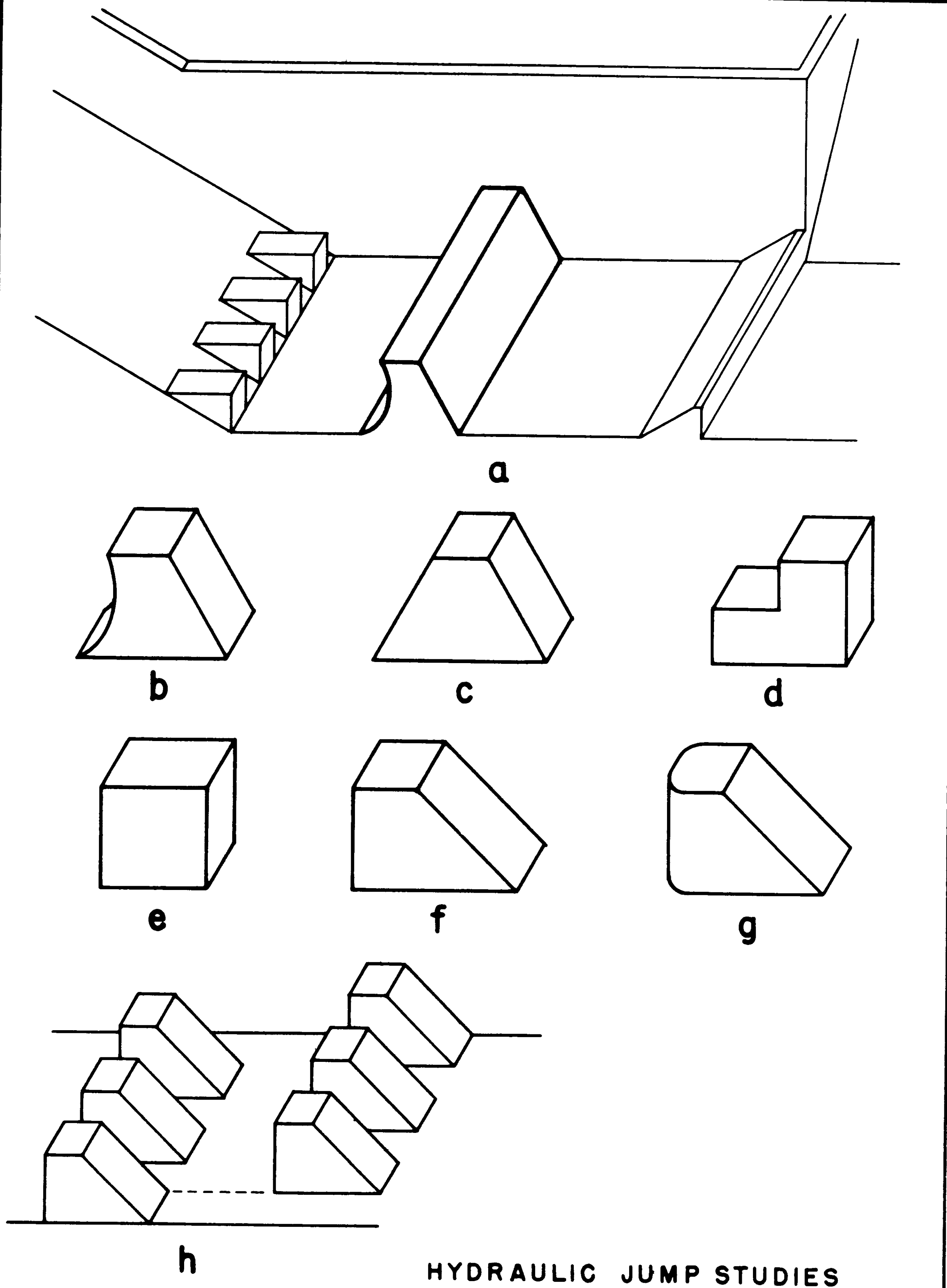
LENGTH OF JUMP ON HORIZONTAL FLOOR

437



HYDRAULIC JUMP STUDIES

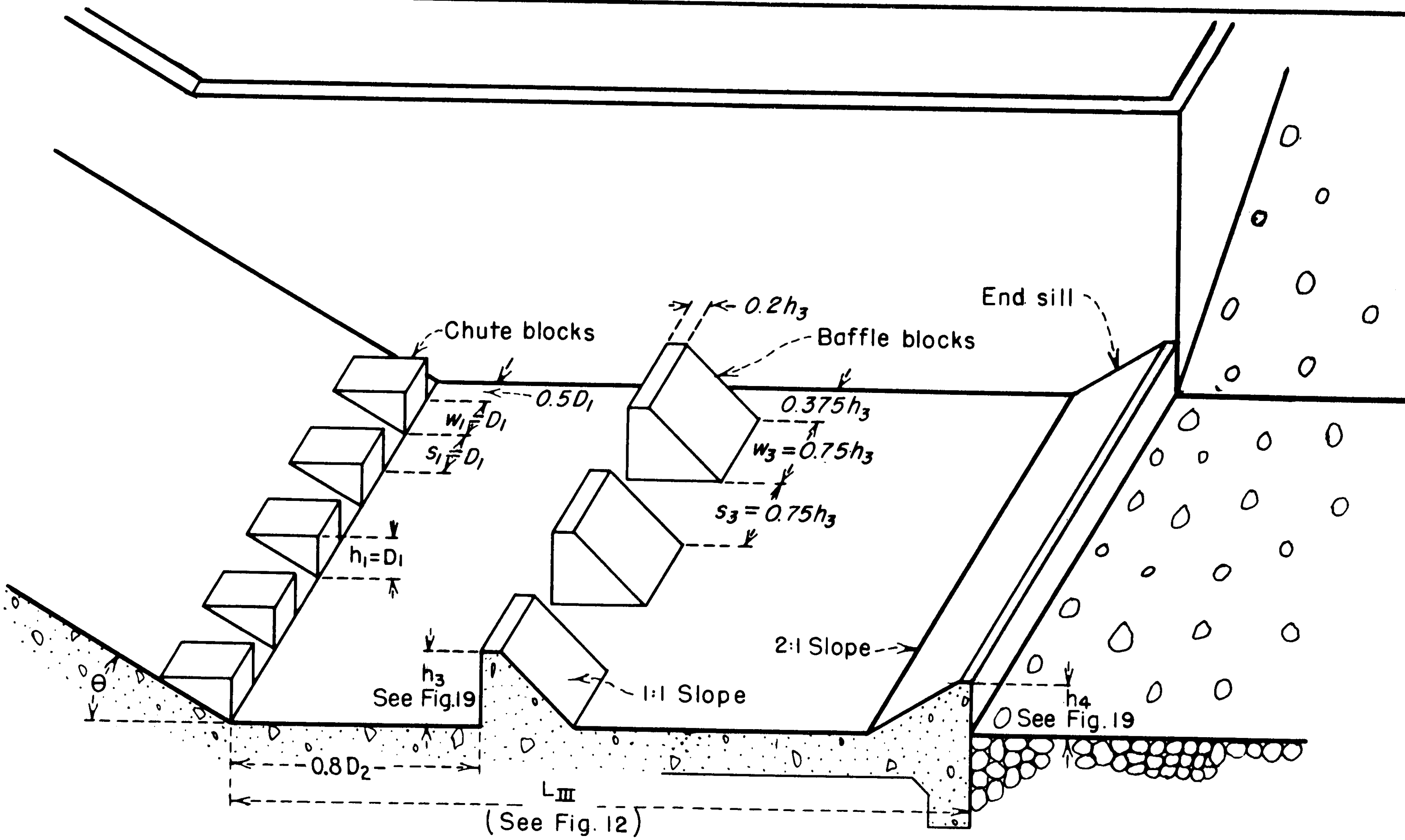
SAF STILLING BASIN



HYDRAULIC JUMP STUDIES

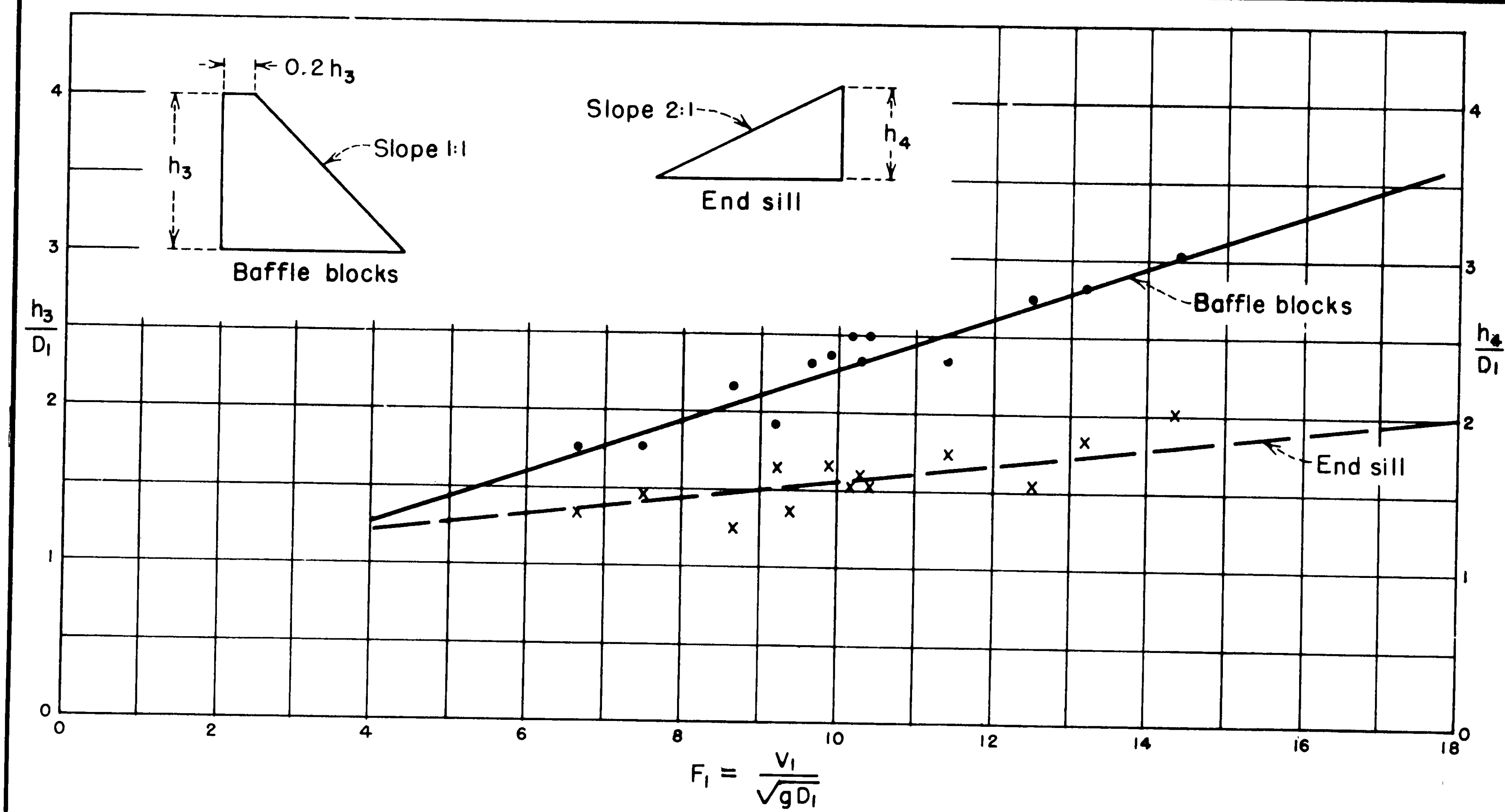
RECORD OF APPURTENANCES

BASIN III



HYDRAULIC JUMP STUDIES
STILLING BASIN III
RECOMMENDED PROPORTIONS

437



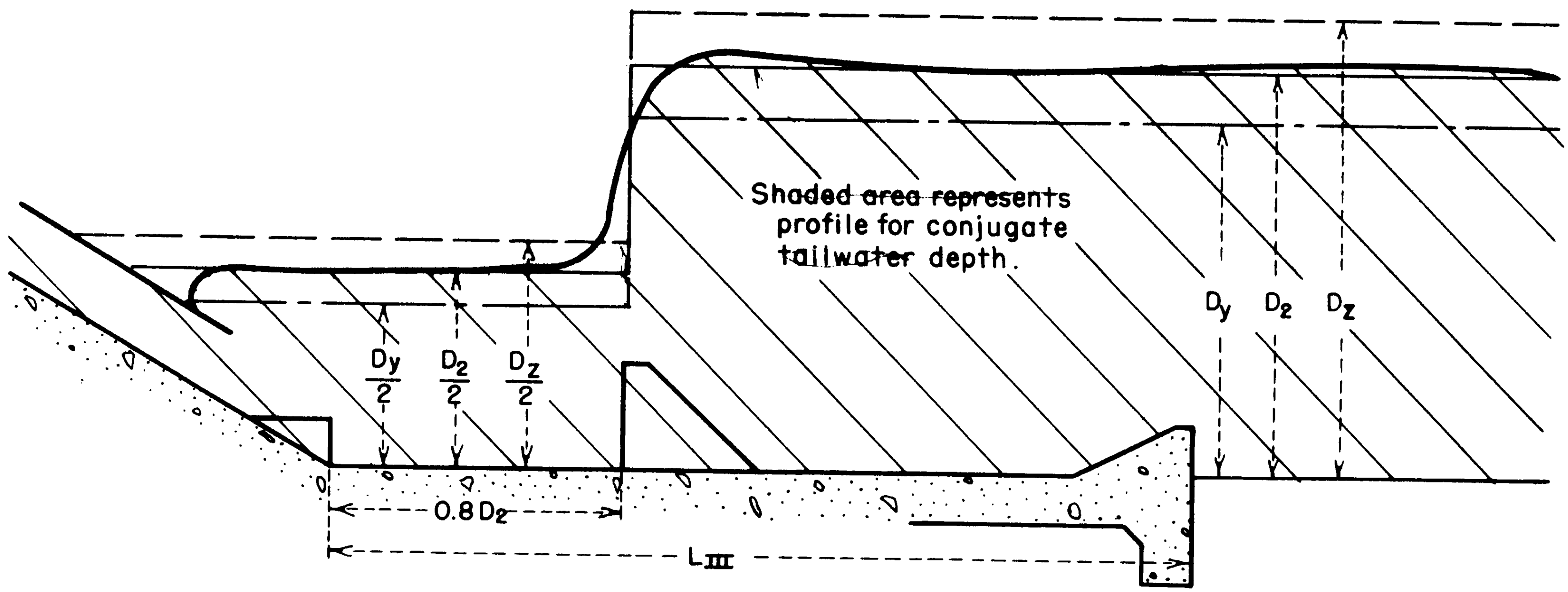
HYDRAULIC JUMP STUDIES

STILLING BASIN III

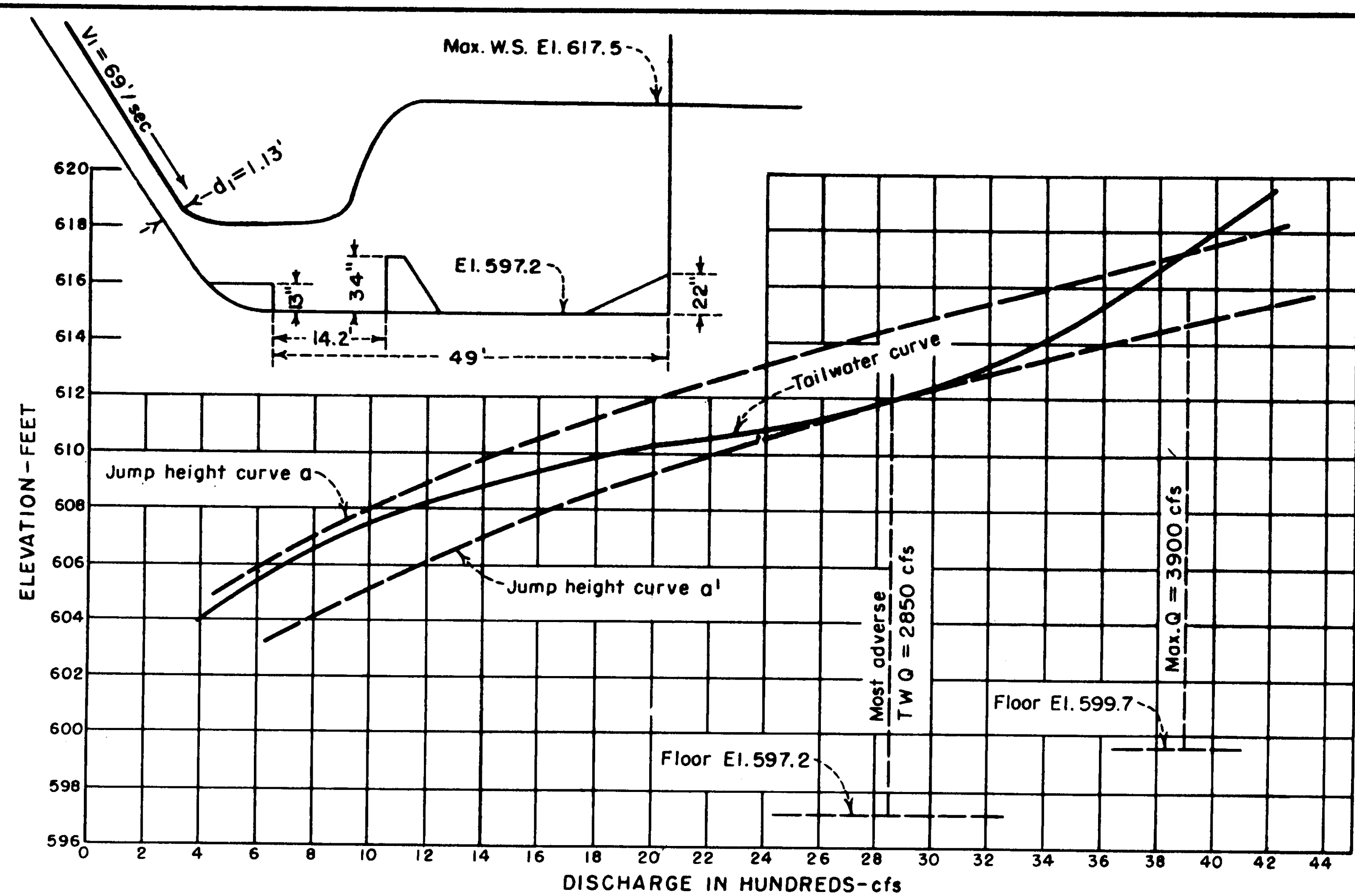
HEIGHT OF BAFFLE BLOCKS AND END SILL

437

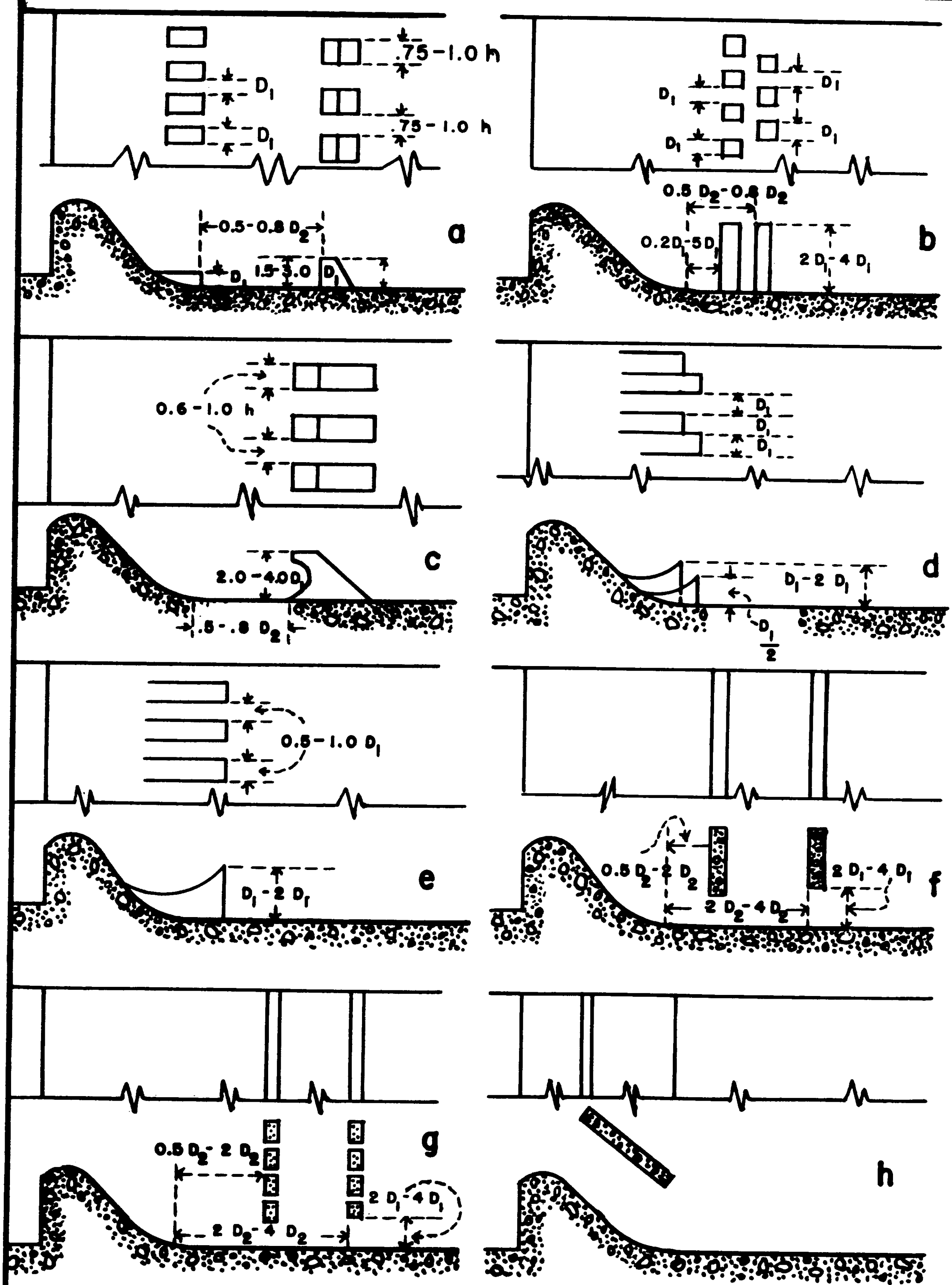
FIGURE 19



HYDRAULIC JUMP STUDIES
STILLING BASIN III
APPROXIMATE WATER SURFACE AND PRESSURE PROFILES



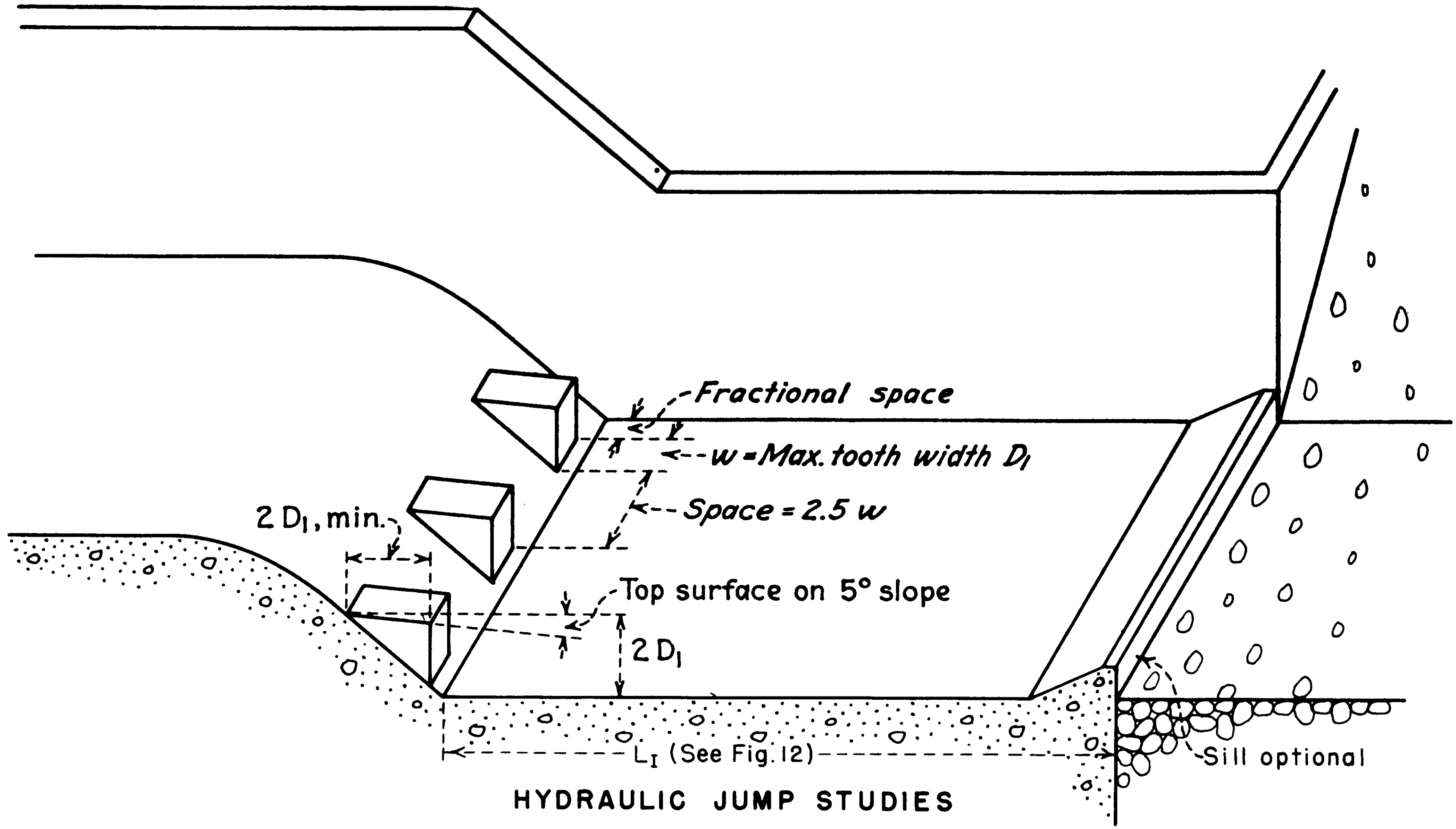
HYDRAULIC JUMP STUDIES
STILLING BASIN III - EXAMPLE 3
TAILWATER AND JUMP HEIGHT CURVE



HYDRAULIC JUMP STUDIES

RECORD OF APPURTENANCES

BASIN IV.



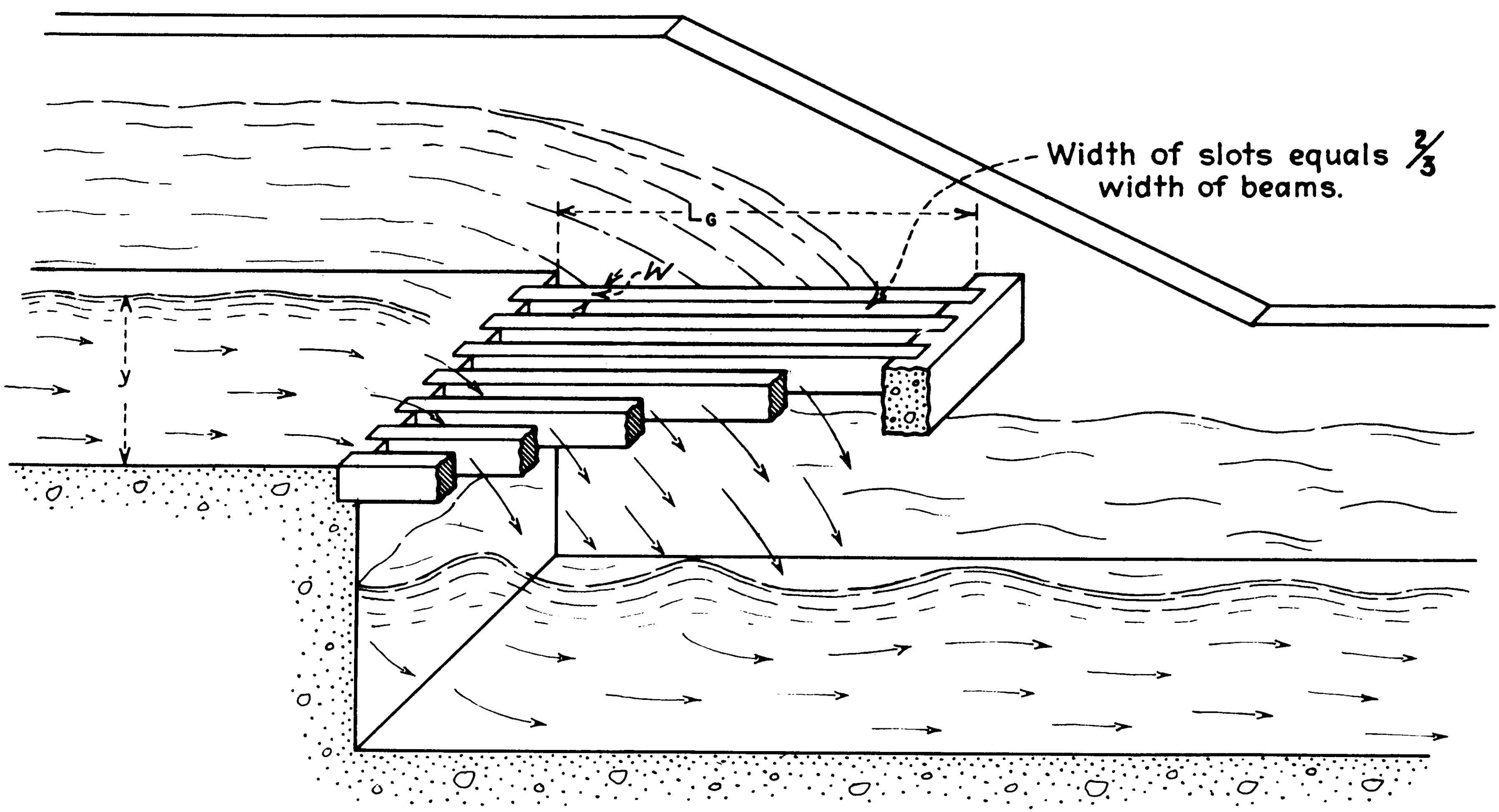
HYDRAULIC JUMP STUDIES

STILLING BASIN IV

FOR F_1 2.5 – 4.5

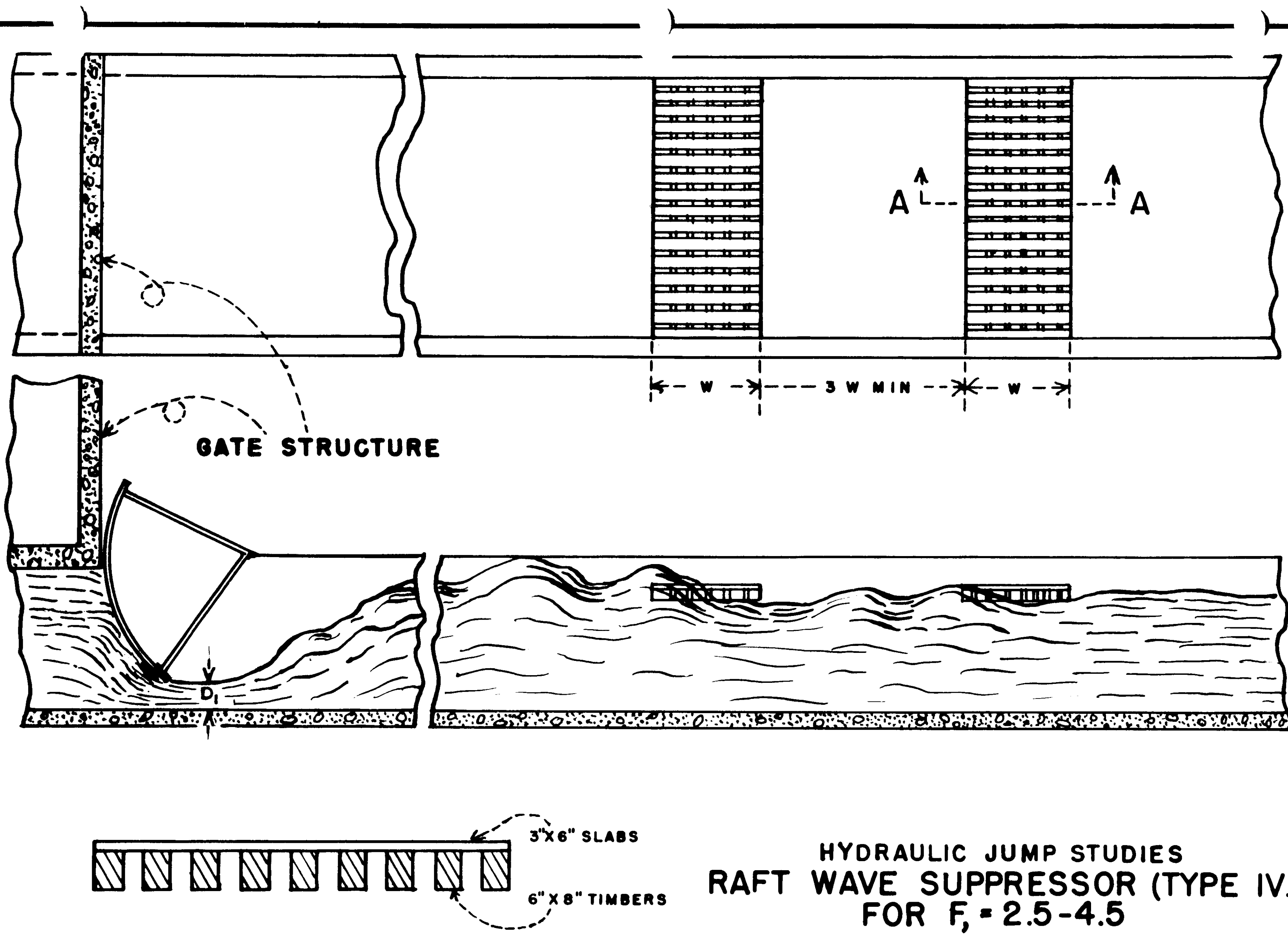
437

FIGURE 23



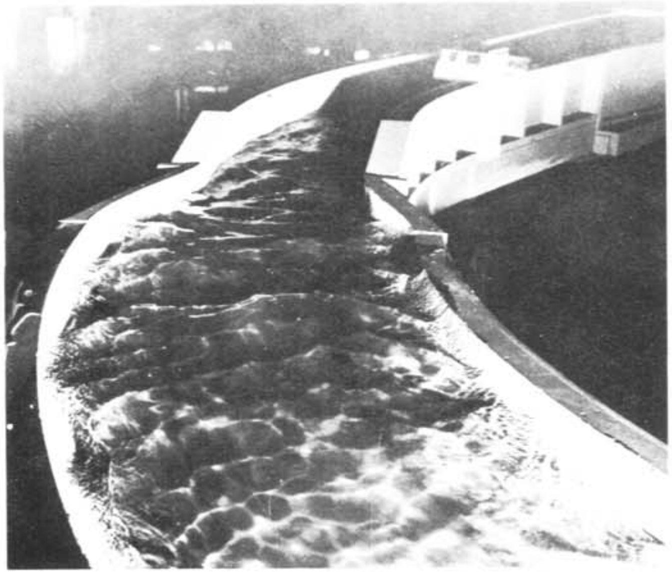
HYDRAULIC JUMP STUDIES

DROP ENERGY DISSIPATOR (TYPE IV)
FOR F 2.5–4.5

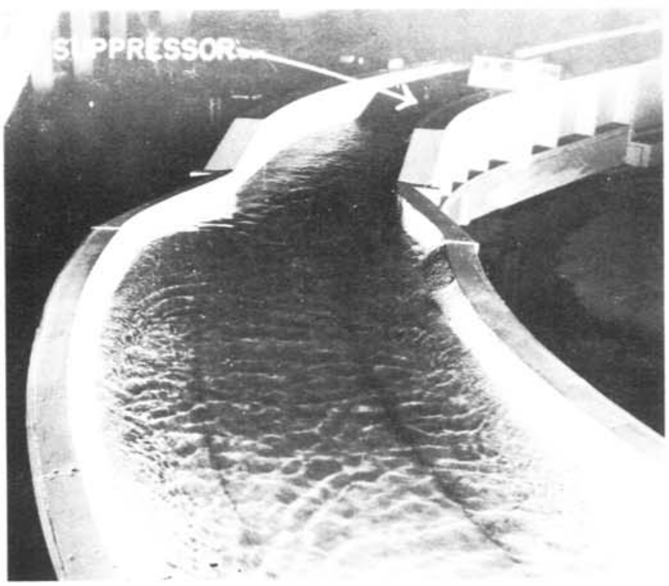


HYDRAULIC JUMP STUDIES
RAFT WAVE SUPPRESSOR (TYPE IV.)
FOR F_1 = 2.5-4.5

437



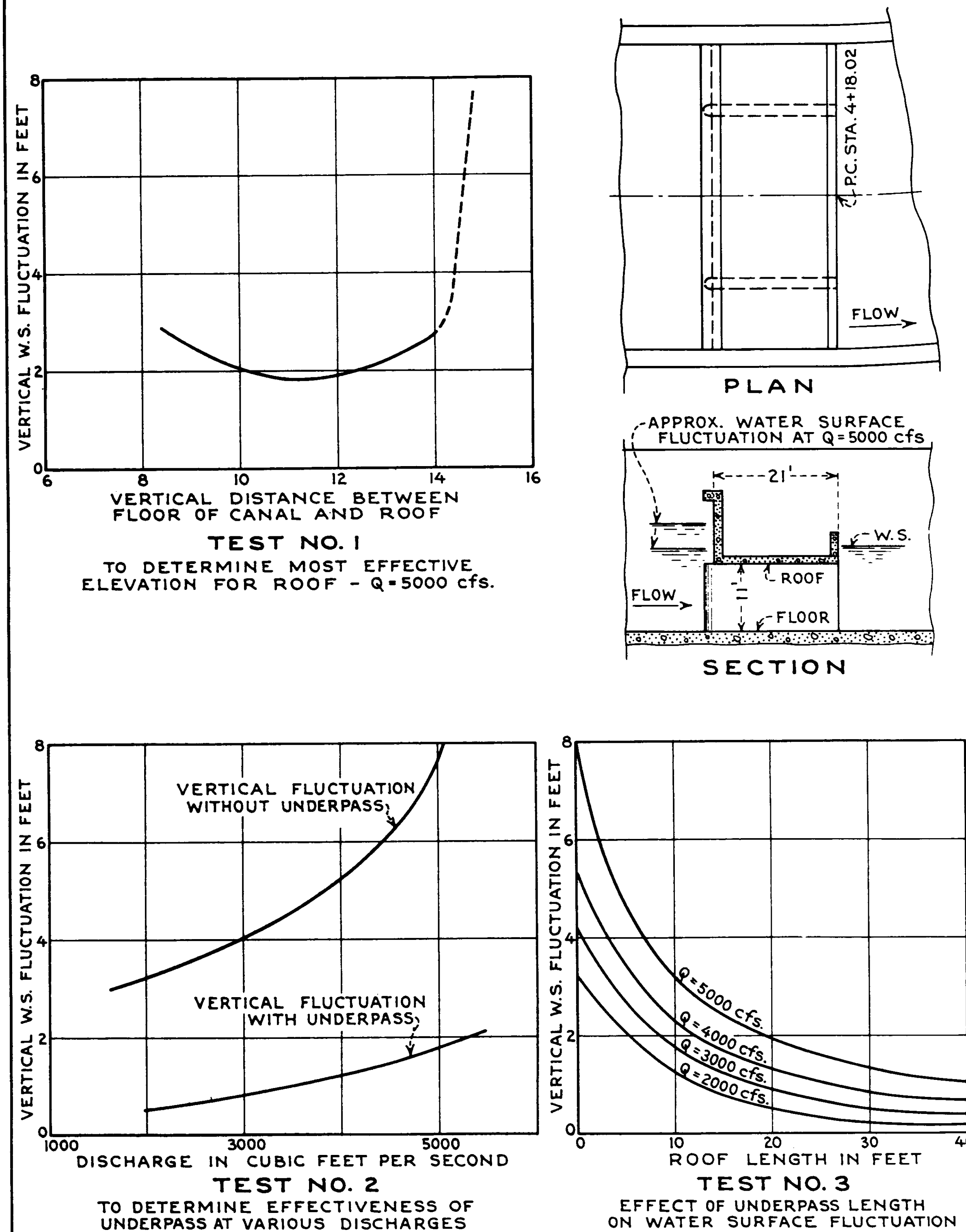
Without suppressor - waves overtop canal.



Suppressor in place - Length $1.3D_2$, submerged 30 percent

Performance of Underpass Wave Suppressor
1:32 Scale Model
Discharge 5,000 Second-feet

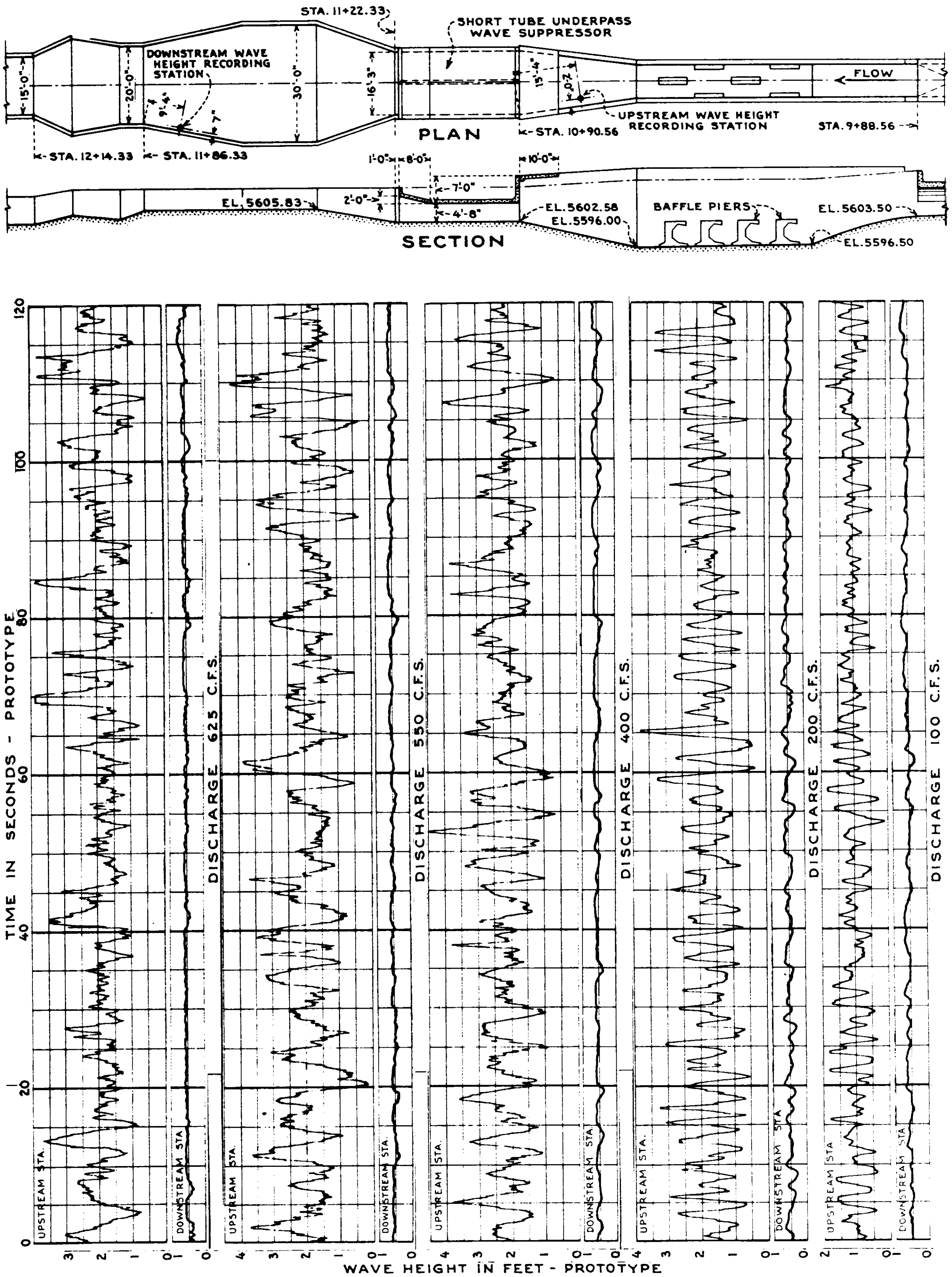
FIGURE 27



WAVE SUPPRESSOR FOR

FRIANT - KERN CANAL

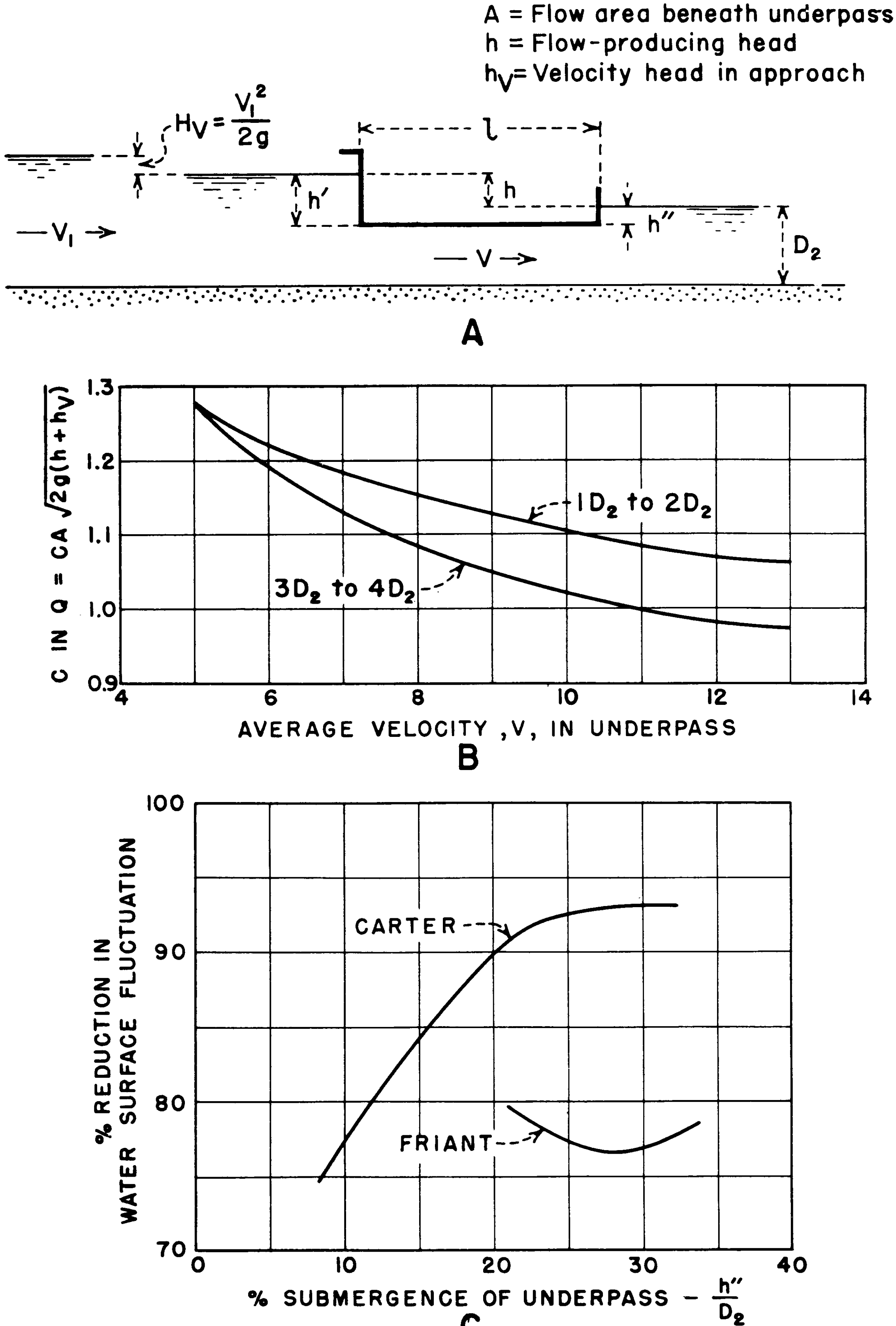
RESULTS OF HYDRAULIC MODEL TESTS



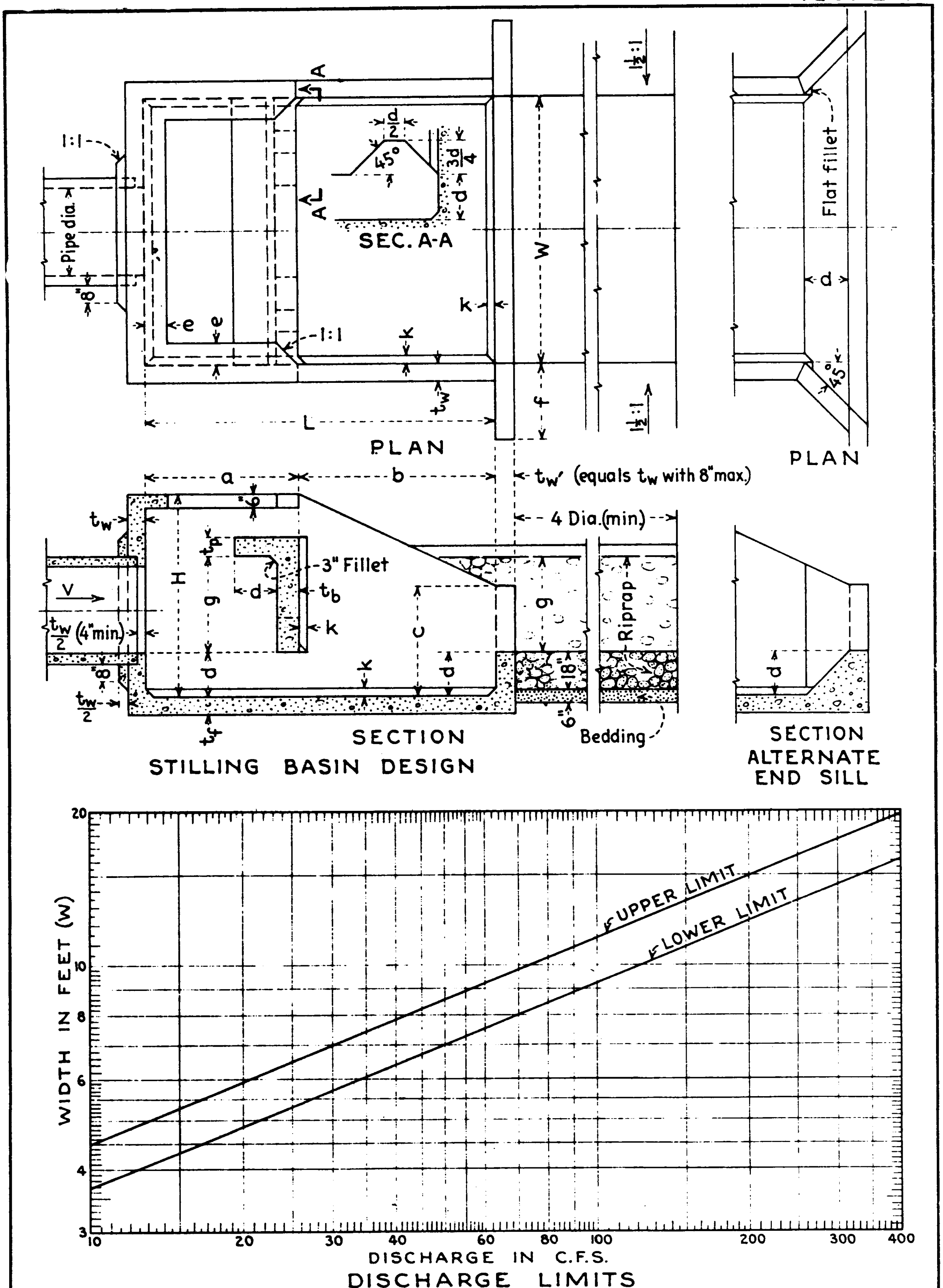
CARTER LAKE DAM NO. 1 • OUTLET WORKS

WAVE HEIGHT RECORDS

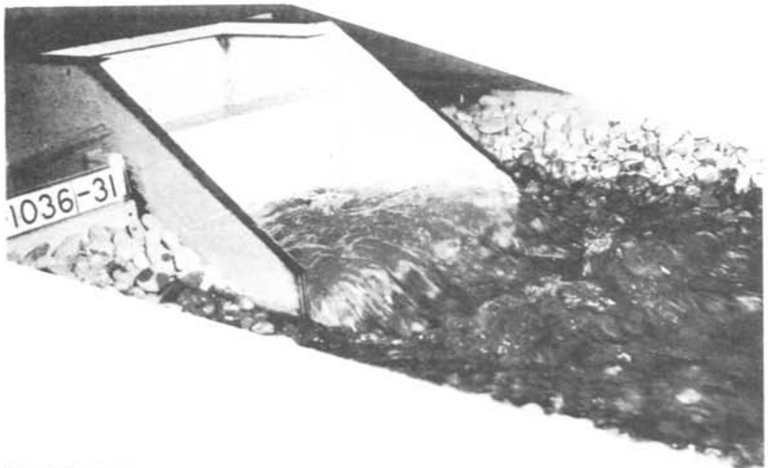
(MODEL SCALE 1:16)



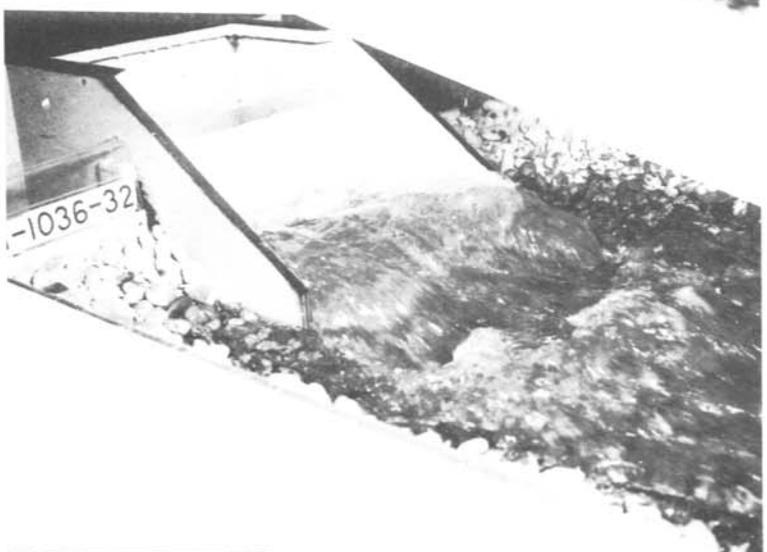
HYDRAULIC CHARACTERISTICS UNDERPASS WAVE SUPPRESSOR



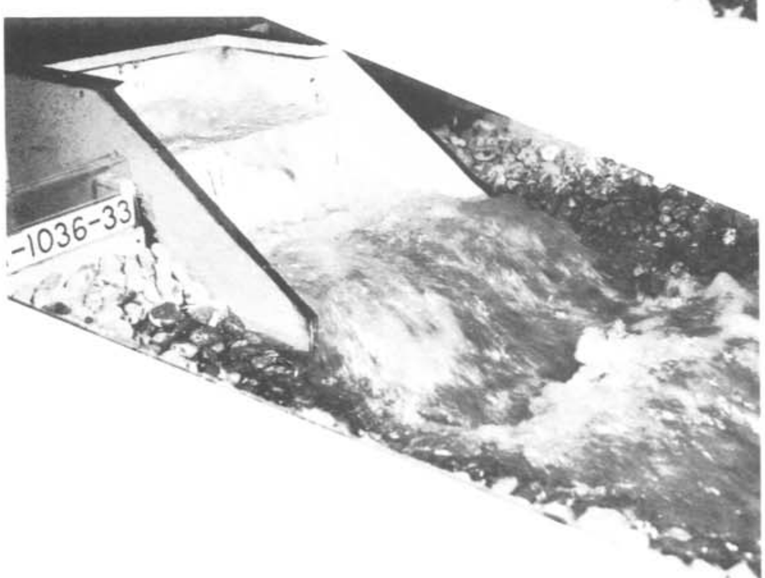
IMPACT TYPE ENERGY DISSIPATOR
(BASIN VI)



Lowest value of maximum discharge - Corresponds to upper limit curve

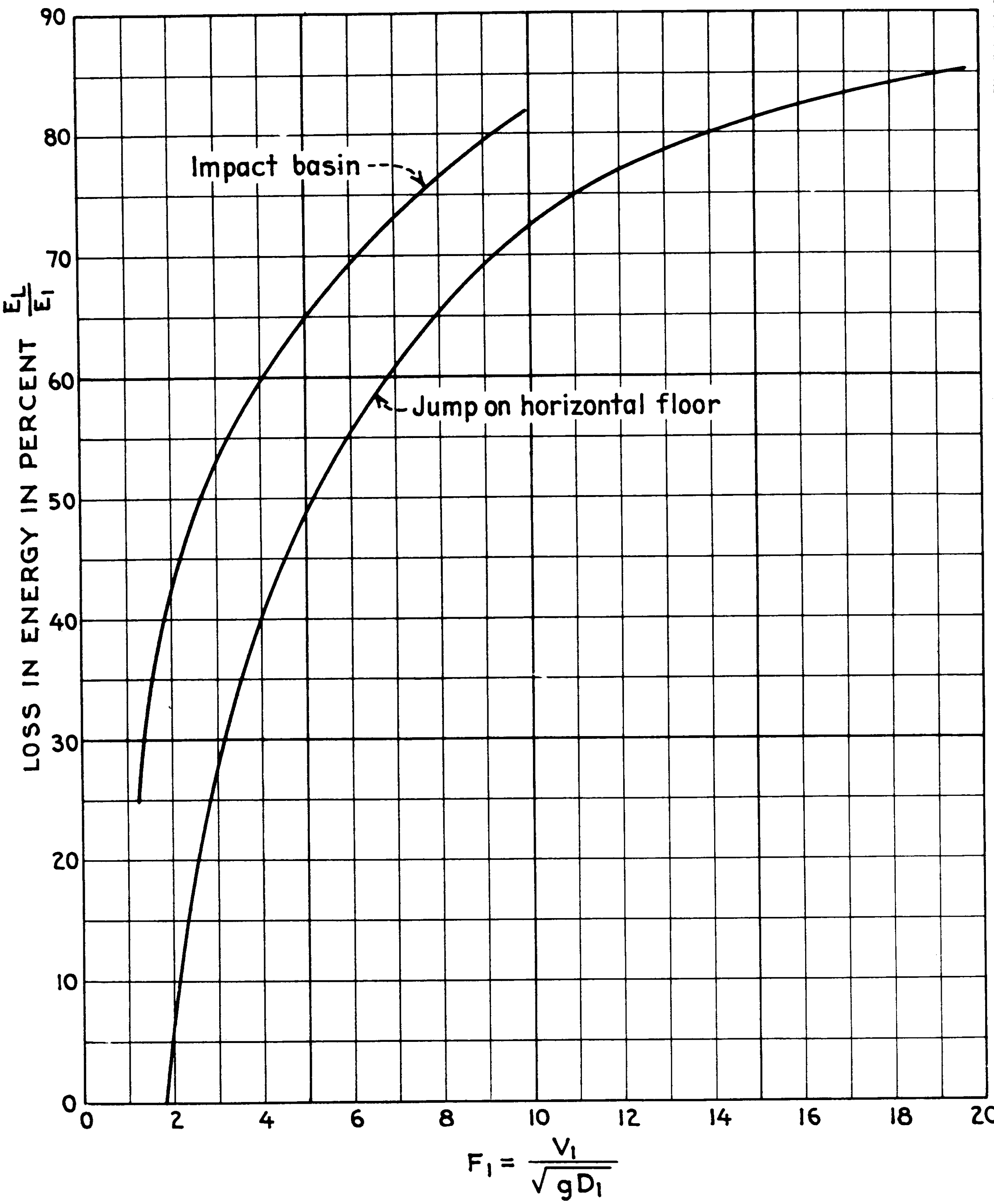


Intermediate value of maximum discharge - Corresponds to tabular values

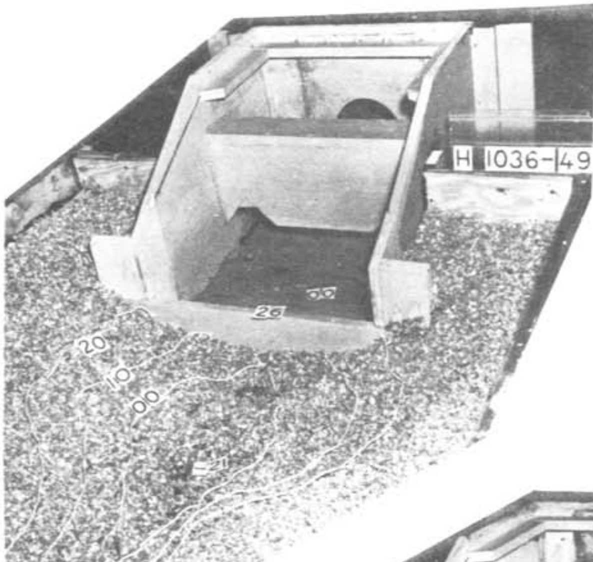


Largest value of maximum discharge - Corresponds to lower limit curve

Typical Performance at Maximum Discharges - No Tailwater
Impact Type Energy Dissipator - Basin VI

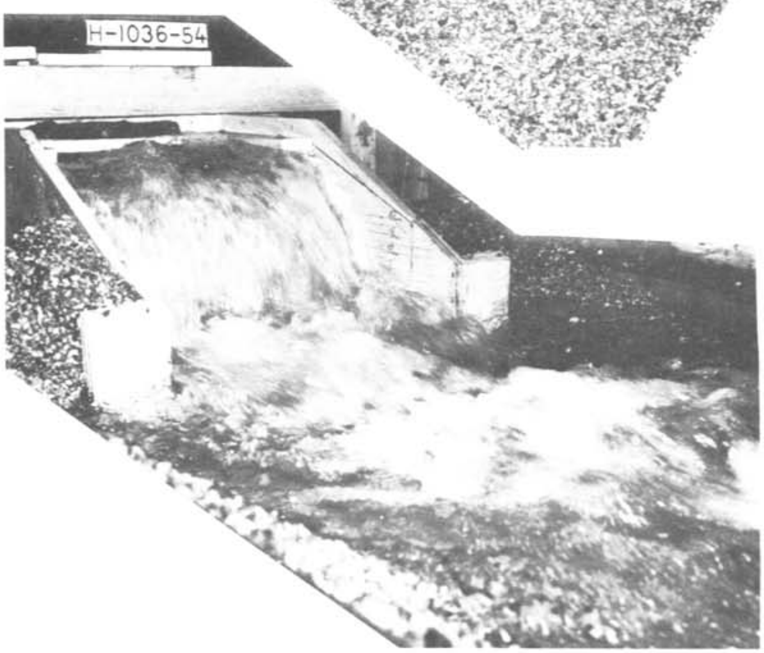


COMPARISON OF ENERGY LOSSES
IMPACT BASIN AND HYDRAULIC JUMP



A. Erosion of channel bed-standard wall and end sill.

B. Less erosion occurs with alternate end sill and wall design.



C. Flow appearance when entire maximum discharge passes over top of baffle during emergency operation.

Channel Erosion and Emergency Operation for Maximum Tabular Discharge
No Tailwater
Impact Type Energy Dissipator - Basin VI

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