UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

DEVELOPMENT OF AN ENERGY ABSORBER SUITABLE FOR INSTALLATION IN CONNECTION WITH LARGE TURBINES OPERATING UNDER HIGH HEADS

By

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And

G. J. Hornsby, Engineer

August 10, 1939

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MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: DEVELOPMENT OF AN ENERGY ABSORBER SUITABLE FOR INSTALLATION IN CONNECTION WITH LARGE TURBINES OPERATING UNDER HIGH HEADS

By

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Denver, Colorado,

August 10, 1939

PREFACE

The hydraulic model studies made in connection with the development of this energy absorber, as described in this report, were made in the power and pumping plant section of the hydraulic laboratory under the direction of G. J. Hornsby, engineer. The development of the design is the work of G. J. Hornsby, engineer, assisted by Harold D. Briley, junior engineer, who also had charge of the construction and testing of the model.

These studies were made under the general supervision of J. L. Savage, chief designing engineer, and Arthur Ruettgers, senior engineer. All engineering work of the Bureau of Reclamation is under the direction of R. F. Walter, chief engineer, and all activities of the Bureau are under the direction of John C. Page, commissioner.

INTRODUCTION

1. History and description. The fact has long been accepted that it is necessary to equip all large hydraulic turbine power units with a regulating device connected to the governor regulating mechanism which will suddenly and effectively function if and when for any reason the wicket gates on the turbine should close, due to mechanical or load failure. That this separate unit be simple and positive in action yet be strong and rugged enough to withstand the shock of a sudden operating condition and continued use as a separate regulating device if required, is the accepted design criterion.

In previous tests on models of relief valves and energy absorbers as described in technical memorandum No. 578, the purpose was to study the performance of machines already in operation at Boulder Dam and devise means of correcting certain objectionable features. The energy absorbers tested were designed and built by two different manufacturers, and while each apparently recognized that the dissipation of energy is most easily effected by spreading the jet and avoiding energy concentrations, they used different methods of approach. The one used a needle-type relief valve which concentrated the energy in a huge jet and depended upon a conical baffle set in the body of the energy absorber to do the spreading, the other used an umbrella-type valve which spread the water at the point of discharge from the valve. Both types were subject to cavitation and were troublesome to aerate successfully. Unstable

flow, chatter, and vibration were objectionable features which were difficult to reduce to tolerable values.

After considerable study of the problem at hand the laboratory staff was convinced that it was possible to design an energy absorber which would be free from the objectionable features of the earlier designs. With this in view a new and different method of spreading the jet from the valve and absorbing the energy was evolved. An energy absorber model embodying these new principles was designed and tested in the laboratory.

2. Scope of tests. This model of the energy absorber was studied qualitatively and quantitatively in order to determine definitely the requirement for a stabilized flow within the lower chamber employing air at atmospheric pressure to help prevent cavitation, vibration, and to stabilize the flow through the valve.

SUMMARY

3. Results and conclusions. The results obtained from the model and field tests on the types of energy absorbers as designed for installation at Boulder Dam indicated definitely that marked improvements could be made. After the series of tests as described in this report were finished the following conclusions have been drawn: (1) If the area of low pressure is concentrated and sufficient air at atmospheric pressure allowed to reach this area the noise of cavitation and vibration to the unit will be minimized. In this case it is necessary to provide two air vents for this purpose, one to aerate the exterior of the jet as it leaves the valve seat and the

other to aerate the interior of the jet through the main valve via the pilot valve stem. (2) That the simplest, safest, and most efficient means of spreading the jet as it leaves the valve, is the rotating motion induced in the water by the semiscroll-type valve chamber. (3) That a single bowl if correctly designed is sufficient for installations up to 600-foot heads. (4) The remainder of the unit must be of a sufficient size so as not to restrict the flow thus causing an increase in the velocity.

Finally from a study of the visual and actual test data which are presented in this report it is definitely believed that a suitable energy absorber has been developed for installation in connection with large turbines operating under high heads.

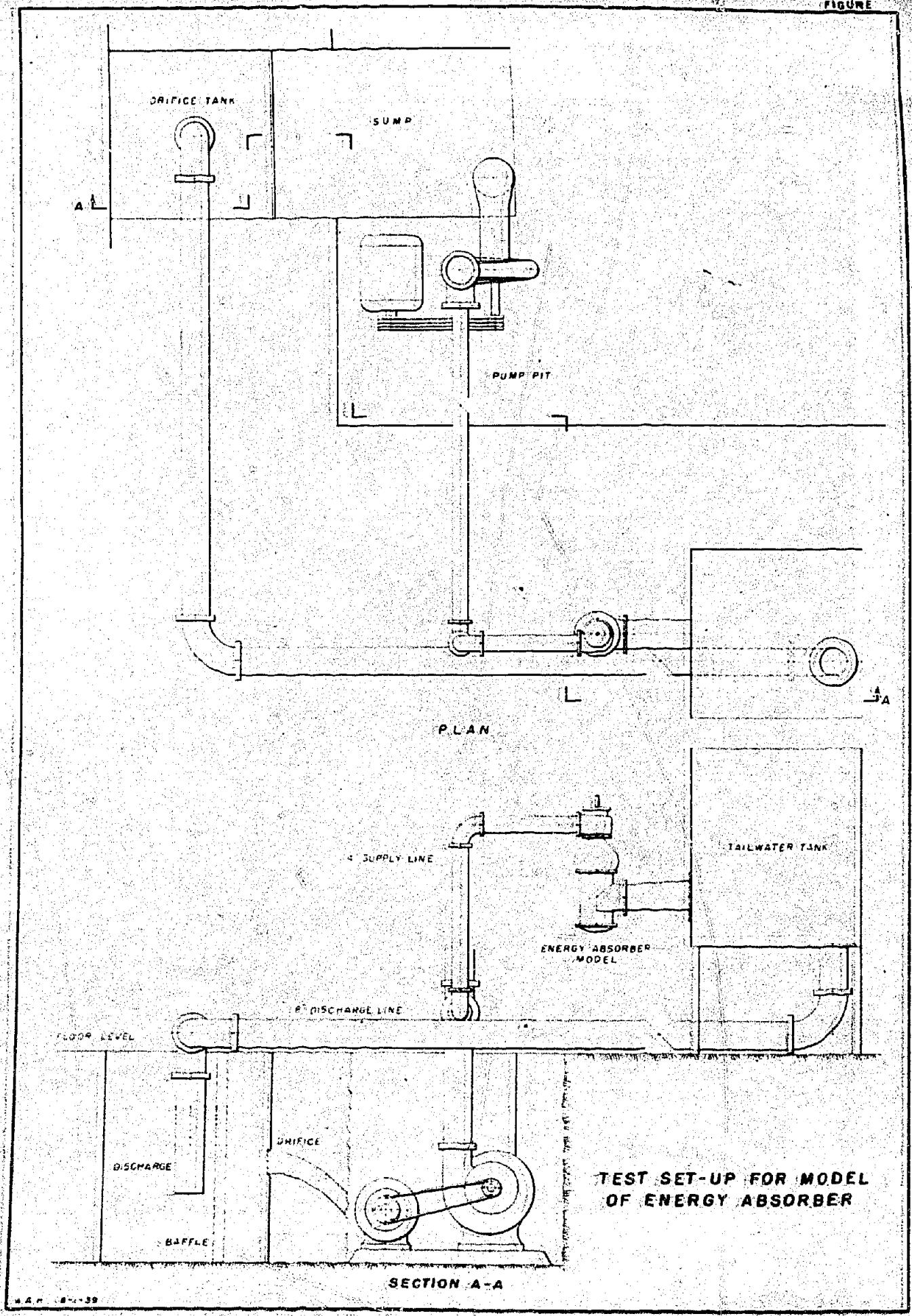
MODEL TESTS

4. The principle involved. It was reasoned that the energy released by the valve could be absorbed by properly directing the flow of the water through the valve and the absorber without the use of baffles of any sort. Spreading the jet was accepted as one of the most effective means of controlling the released energy. It was known that the jet issuing from the valve orifice would spread of its own accord if it could be given a rotary motion as it entered the orifice. In order to accomplish this it was necessary to construct the valve body in the form of a scroll. The rotary motion thus set up continued through the orifice and formed a cone having its apex in the orifice. This cone of flowing water was collected in a bowl-shaped chamber which conducted the flow through a larger

orifice into the lower body of the absorber.

5. Description of the model. (a) General.—The model of the energy absorber was constructed in the Denver hydraulic laboratory which is located in the basement of the Customhouse building. As related to the Boulder Dam units, the scale ratio used for this test was 20 to 1. The water was supplied to the model through a 4-inch supply line by an 8-inch centrifugal pump, through a recirculating system, with the flow controlled by a gate valve (figure 1). The tailwater level was also controlled by a gate valve located below the tailwater box. The discharge was measured by means of an orifice located in the return flume to the pump sump. The head on this orifice was measured by allowing the water to rise in a glass tube which was mounted on a graduated scale. The pressure in the supply line was measured near the entrance to the model by means of a mercury U-tube. The negative values within the model were also measured by use of mercury U-tubes. In order to have the test material available for later study and demonstration, a complete record of each test was made by use of the slow-motion moving-picture camera, which due to the scale ratio, reduced the model velocity to very near that of the prototype. All dimensions and data as shown in this report on the tables or figures are true model dimensions and values, as this model does not apply to a specific case but is based on a general design. References as to head either as recorded or as used in the formula refer to static head only. The values of "C" as given in the tables and as shown graphically on the curve sheets were determined

FIGURE



TEST SET-UP FOR MODEL OF ENERGY ABSORBER

from the formula $C = \frac{Q}{A\sqrt{2GH}}$ in which C is the coefficient of discharge, Q the measured discharge, A the area at the valve, G the force of gravity and H the measured static head.

(b) The semiscroll-type relief valve.--The entire housing and valve assembly was cast and machined from brass (figure 2). The housing was of the shape of a semiscroll as shown on the drawing. The main valve is free acting; that is, its movement is controlled only by the small pilot valve which is in turn actuated by the governor operating mechanism.

(c) Receiver bowls.--1. Double-bowl type.--The receiver bowls were formed of pyralin and connected to the brass valve body immediately below the main valve seat. The first type tested (figure 2) was a double bowl consisting of two different sizes of circular bowls, the smaller resting on top of the larger, which was in turn connected to the vertical part of the T-discharge passage.

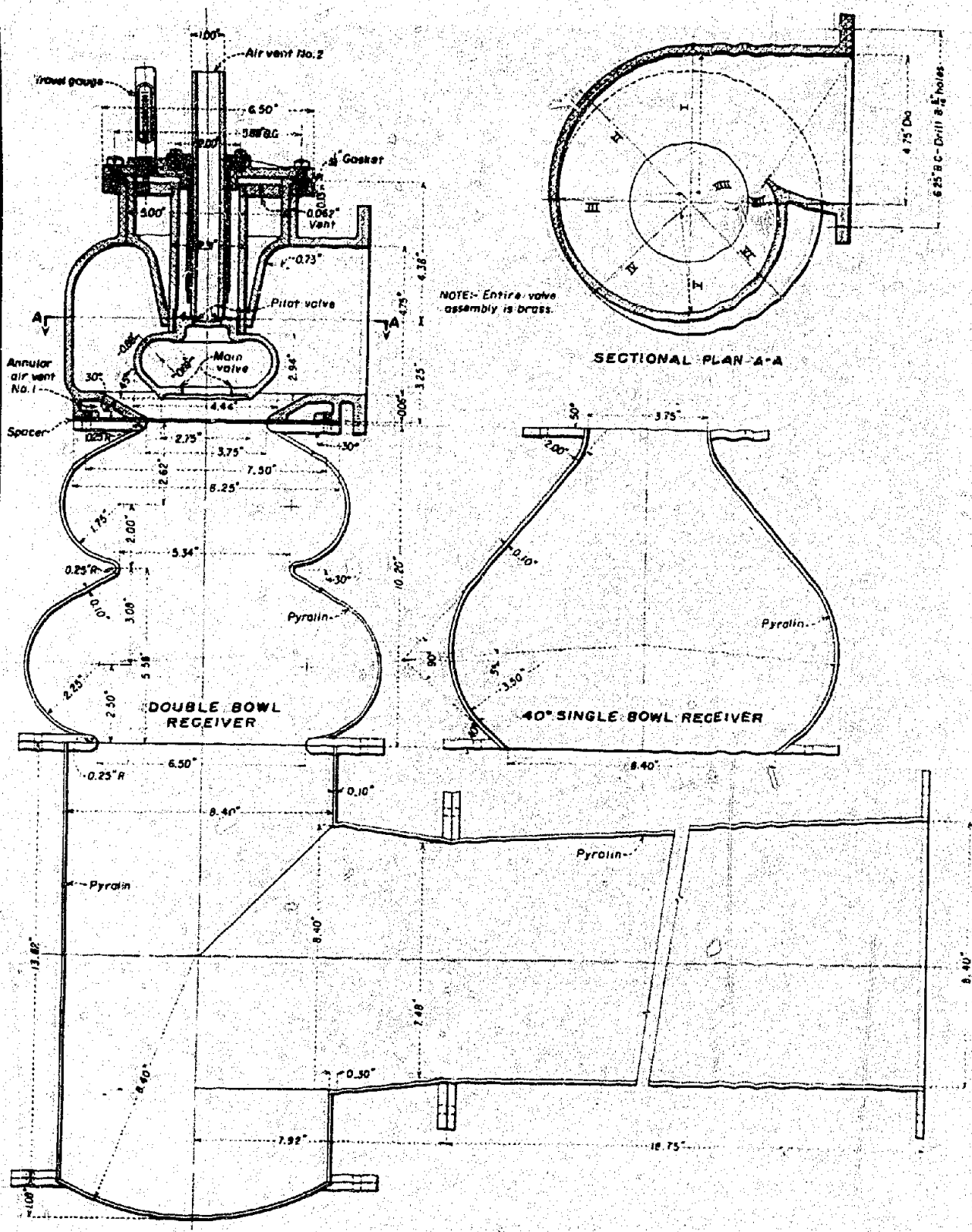
2. 40-degree single-bowl type.--The second receiver bowl tested was also formed of pyralin, had the same vertical length, and occupied the same place in the model as the double-bowl type.

DISCUSSION OF RESULTS

Initial Studies

6. Tests 1-12 -- Double-bowl receiver. The first studies to be made on this development were directed primarily toward the effect to be achieved by use of the double bowl which was located below the main valve seat. The details of this design as shown on

FIGURE 2



ASSEMBLY OF ENERGY ABSORBER MODEL

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figure 2 were worked out in connection with the details of the semi-scroll-type valve with the thought that the water having been given an initial outward whirl by the scroll would tend to follow the contour of the receiver. It was believed that if this could be effected that the change in direction and the distance traveled would be sufficient to dissipate the contained energy so that no ill effect would be evident beyond the discharge into the tailrace.

In order to determine the type of lower discharge chamber best suited to this type of valve and receiver bowl, provisions were made on the model by which the bottom of the vertical chamber below the receiver bowl could be made flush with the bottom of the discharge tube or else be recessed below the inlet to this tube. A comparison of the results obtained with the bottom in these two positions is given in table 1.

Under the entire range of model heads as tested, signs of cavitation and vibration were observed. This area of low pressure (area of probable cavitation) occured as anticipated, immediately below the valve seat. Preliminary studies had indicated that if this area of low pressures could be centralized and then air at atmospheric pressure be permitted to enter and diffuse within the flowing water, the possibility of excess cavitation, vibration, or unstable flow would be minimized. The first tests on this type (tests 1-4) so indicated; that is, noise of cavitation was evident, vibration was noticeable, and unstable or surging flow was observed. Even though the measured discharge was greater than expected, the coefficient of

ENERGY ABSORBER TEST DATA

TEST No.			1-4		5-8		9-12		13-16		17-20		21-24		25-28	
RUN No.	STATIC HEAD FEET	VALVE OPEN-ING	FLUSH FLAT BOTTOM,				RECESSED BOTTOM		FLUSH FLAT BOTTOM				RECESSED BOTTOM			
			NO AIR		AIR		NO AIR		NO AIR		AIR		NO AIR		AIR	
			Q	C	Q	C	Q	C	Q	C	Q	C	Q	C	Q	C
1	20	.2	0.56	1.12	0.48	0.98	0.52	1.06	—	—	—	—	—	—	—	—
2		.4	1.07	1.04	0.94	0.91	1.04	1.01	1.06	1.03	0.77	0.74	0.97	0.94	0.89	0.87
3		.6	1.41	0.96	1.26	0.86	1.38	0.94	1.52	1.04	1.09	0.74	0.90	0.68	1.18	0.81
4		.8	1.55	0.82	1.35	0.72	1.51	0.80	1.57	0.83	1.35	0.72	1.08	0.57	1.36	0.72
5		1.0	1.60	0.65	1.37	0.56	1.55	0.63	1.57	0.64	1.42	0.58	1.09	0.44	1.41	0.57
1	15	.2	0.46	1.08	0.46	1.08	0.45	1.04	—	—	—	—	—	—	—	—
2		.4	0.90	1.01	0.83	0.93	0.88	0.98	0.89	1.00	0.66	0.74	0.91	1.03	0.81	0.91
3		.6	1.21	0.95	1.05	0.83	1.17	0.93	1.31	1.03	0.93	0.74	0.94	0.74	1.01	0.80
4		.8	1.32	0.81	1.17	0.72	1.29	0.79	1.35	0.82	1.16	0.71	1.04	0.63	1.15	0.70
5		1.0	1.37	0.64	1.18	0.55	1.30	0.61	1.31	0.61	1.21	0.57	1.04	0.49	1.20	0.56
1	10	.2	0.36	1.02	0.37	1.04	—	—	—	—	—	—	—	—	—	—
2		.4	0.71	0.98	0.65	0.90	0.66	0.91	0.65	0.89	0.51	0.71	0.87	1.19	0.62	0.86
3		.6	0.94	0.90	0.82	0.79	0.89	0.86	1.04	1.00	0.75	0.73	0.88	0.85	0.86	0.83
4		.8	1.03	0.77	0.92	0.69	1.02	0.76	1.06	0.79	0.93	0.70	0.95	0.71	0.95	0.71
5		1.0	1.09	0.62	0.94	0.54	1.03	0.59	1.04	0.60	0.98	0.56	0.97	0.56	0.97	0.56
1	5	.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2		.4	0.44	0.85	0.44	0.86	—	—	—	—	—	—	—	—	—	—
3		.6	0.59	0.81	0.56	0.76	0.55	0.74	0.61	0.83	0.41	0.56	0.82	1.12	0.56	0.76
4		.8	0.67	0.71	0.62	0.65	0.64	0.67	0.69	0.73	0.63	0.67	0.84	0.89	0.64	0.67
5		1.0	0.68	0.55	0.63	0.51	0.67	0.54	0.68	0.55	0.67	0.54	0.85	0.69	0.66	0.53

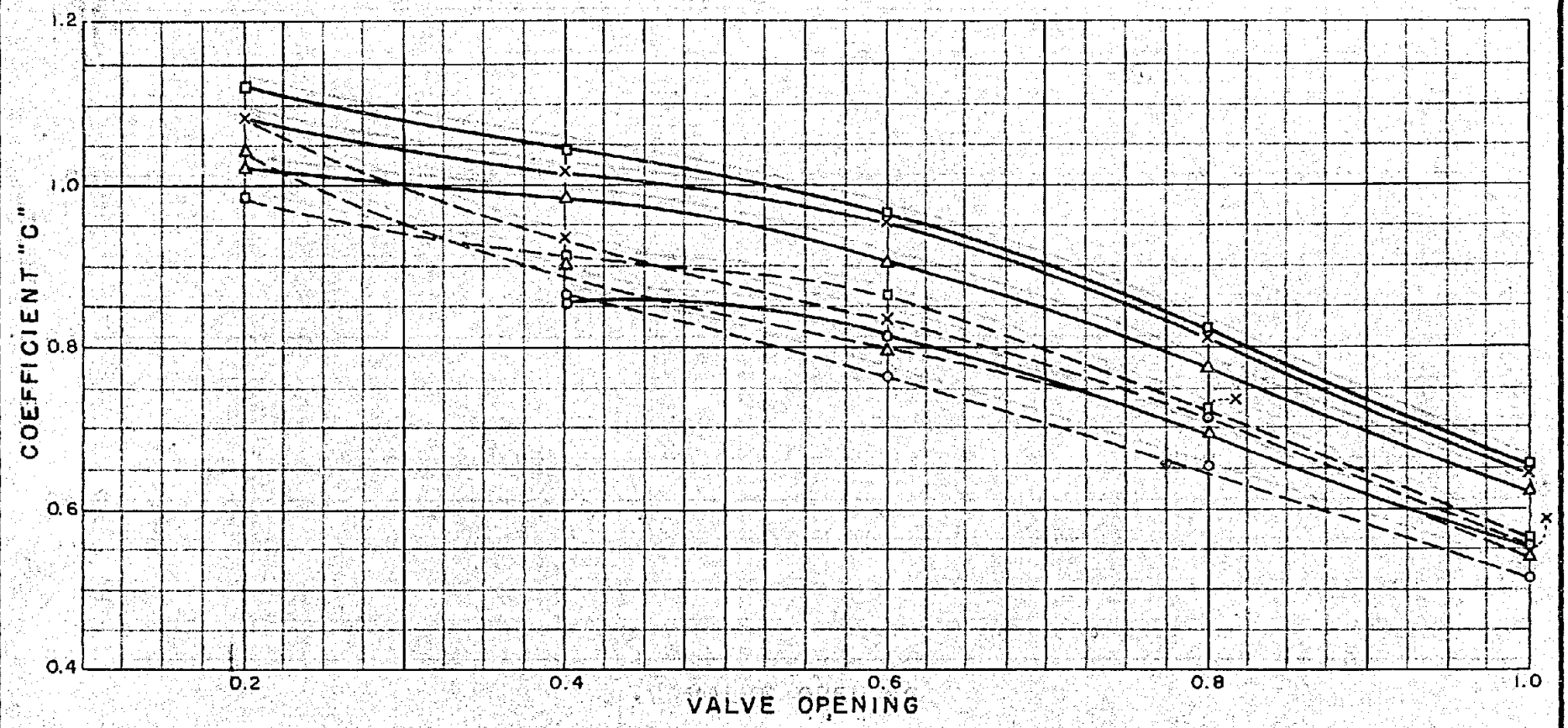
TABLE I

discharge was very irregular, varying from 0.55 to 1.12 in value. It is evident that this range is undesirable, but it indicates that the area of low pressure as anticipated in the design has been centralized. It also showed that the problem was to adequately aerate this area of low pressure, stabilize the coefficient, and design a suitable receiver bowl to finish the process of energy dissipation so well begun by the semiscroll valve design.

In anticipation that it would be possible to centralize this area of low pressure by the proper design and thus relieve this adverse condition by the admission of atmospheric air, two possible air entrance valves had been provided in the design of the semiscroll-type of relief valve. Air-vent valve No. 1 was provided as an annular vent located slightly below the main valve seat at the point where the enlargement into the receiver bowl began. The purpose of this air vent is to aerate the exterior of the jet as it leaves the main valve and thus to reduce the possibility of cavitation and vibration to the shell of the receiver bowl. In parallel with this another air vent was provided, known as air-vent valve No. 2. This valve admits air at atmospheric pressure through the pilot valve and the main valve to the interior of the jet. The main purpose of this air is to reduce possible cavitation and vibration to the main valve and to induce the diffusion of the main jet which, in its breaking-up process, will undoubtedly dissipate some of the energy of the flowing water. That this might be accomplished was indicated by visual observations when the two air valves were opened for tests 5-8 on the model. Observed visually the

first thought was that the energy absorber model was now a quiet, smooth-acting machine as most of the noise of cavitation and evidence of vibration were gone. The admitted air was mixing freely with the water and all seemed to be as planned until closer inspection indicated that the flow from the discharge valve was not symmetrical and that the flow in the receiver bowl was not behaving as anticipated. Nevertheless, data which corresponded to identical conditions as tested without air were obtained and confirmed the suspicions aroused by the later visual observations. This data indicated a reduction in discharge due to the inflow of air which reduced the low-pressure area and thus reduced the effective head. The coefficient was also lowered but the range was not materially affected ranging from 0.51 to 1.08 in value. A graphical comparison of discharge coefficients is shown on figure 3. Since one of the design criteria required a uniform and consistent coefficient, this design of receiver bowl was abandoned after a study of the above-mentioned facts.

7. Free-flow tests on semiscroll-type valve. After the previously described tests had indicated that the design of the double receiver bowl was in error, it was believed that if a single bowl were correctly designed that it would accomplish the desired results. The previous tests had also indicated that the 30° angle of the double bowl was too flat and in order to determine the angle of discharge from the valve the model was dismantled. The piping arrangement was changed and the valve, without the rest of the model, was located over the pump sump. The valve was then visually tested under this condition



EXPLANATION

□ 20' Head △ 10' Head
x 15' Head ○ 5' Head
——— No air admitted
- - - - Air admitted

ENERGY ABSORBER
GRAPHICAL COMPARISON
OF DISCHARGE COEFFICIENTS
DOUBLE BOWL RECEIVER
FLUSH FLAT BOTTOM

FIGURE 3

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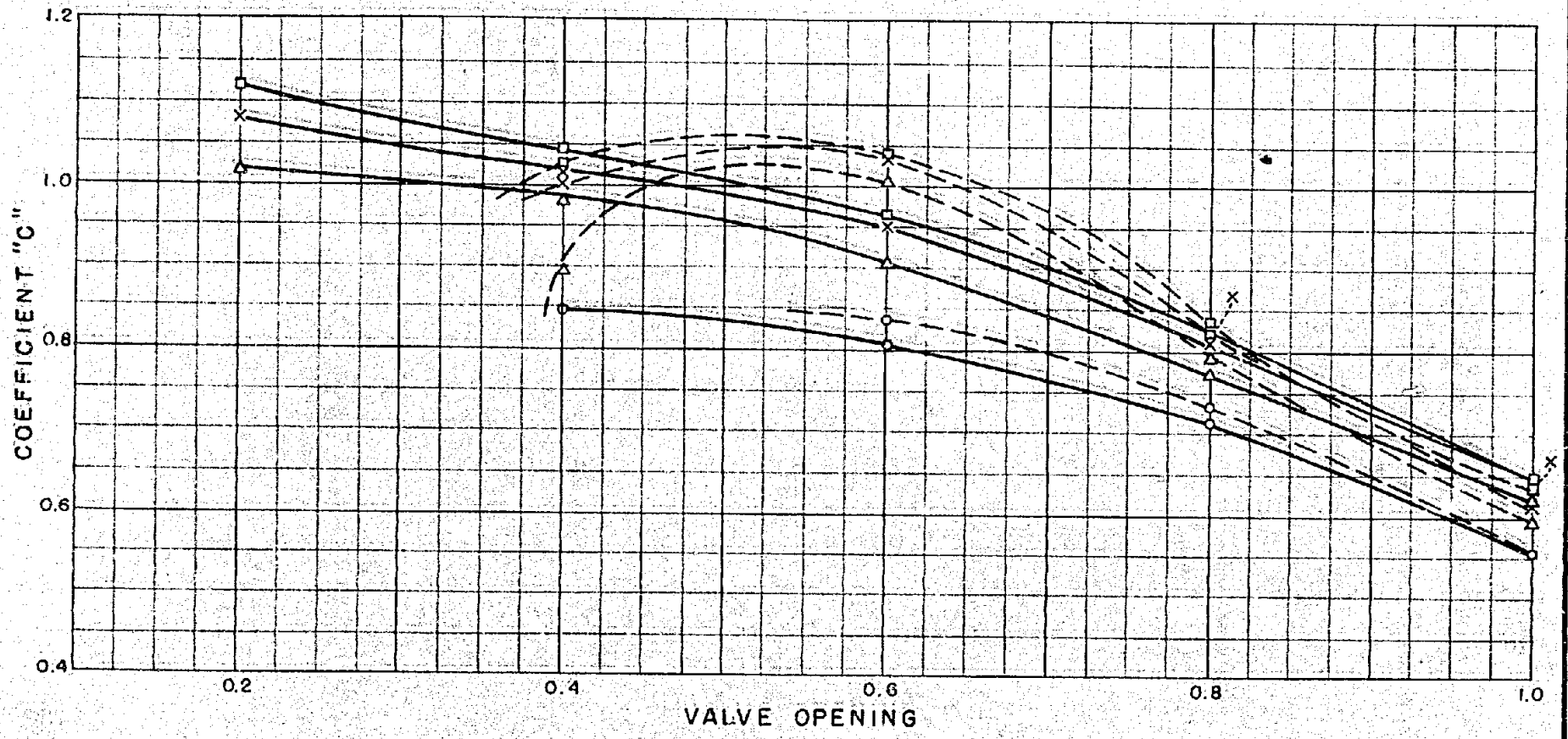
of free discharge and the main conclusion was that the relief-valve design was satisfactory. The angle of discharge from the valve was measured both on the model and from photographs. This angle does not appear to vary appreciable with the head or discharge and was determined to be approximately 45 degrees with the vertical. To assure that there would always be pressure on the sides of the bowl, it was decided that the sides of the single receiver bowl should form an angle of 40 degrees with the vertical.

8. Tests 13-28 - 40-degree single-bowl receiver. The design of the 40-degree single-bowl receiver as decided upon after the previous tests is shown on figure 2. Tests 13-28 correspond to tests 1-12; that is, the only change made is the type of receiver bowl, all other values and parts were unchanged. The first tests (13-16) were made without air being admitted and with the flush flat bottom in place, and visually the same conditions of concentrated low pressure, vibration, and surging flow were evident, but the flow from the valve appeared to be smoother and more even than in the previous receiver. The test data (table 1) indicated almost identical discharges and coefficients as determined before under the same conditions (tests 1-4). A graphical comparison of the discharge coefficients is shown on figure 4. The next series of tests (17-20) on the same type with the flush flat bottom but with air admitted were very encouraging. These tests correspond to tests 5-8 on the double-bowl type of receiver. Although the discharge was slightly less than in the double bowl, this tended to, and did, fairly stabilize the discharge coefficient. The



EXPLANATION

□ 20' Head △ 10' Head
× 15' Head ○ 5' Head
——— Double bowl
- - - - 40° Single bowl

ENERGY ABSORBER

GRAPHICAL COMPARISON
OF DISCHARGE COEFFICIENTS
IN TWO TYPES OF RECEIVERS

FLUSH FLAT BOTTOM
WITH NO AIR ADMITTED

FIGURE 4

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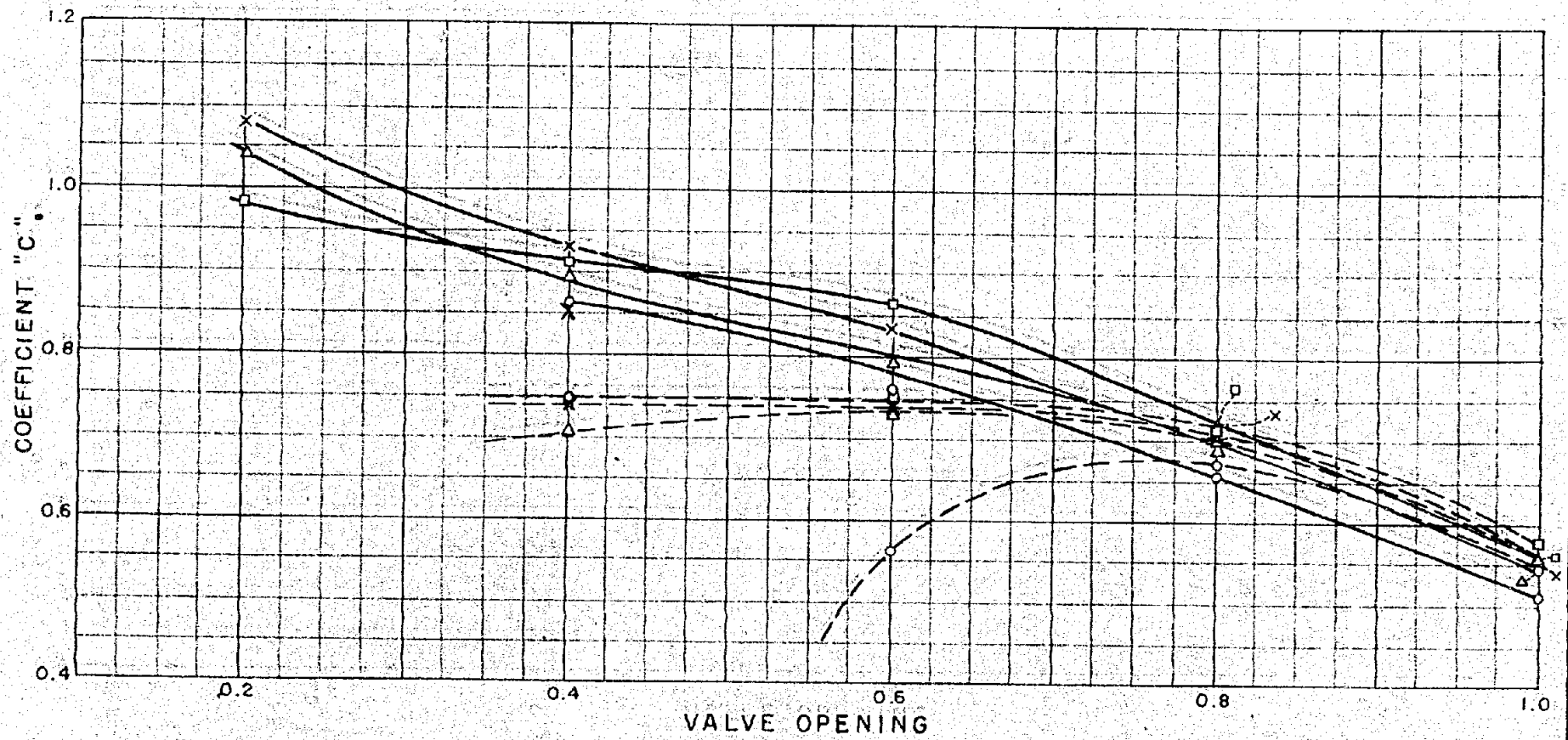
extent to which this was accomplished is shown graphically on figure 5. A comparison of the extent and magnitude of these coefficients as affected by the admission of atmospheric air is also shown graphically on figure 6. Here is definitely shown the effect to be gained by localizing the low-pressure area then admitting air and allowing it to disseminate into the flowing water, which tends not only to equalize but to stabilize the flow.

Due to the fact that the visual observations as made on the double-bowl type with the recessed bottom had appeared satisfactory and in order to have data for comparison, it was decided to conduct a series of tests on this type of receiver with the recessed bottom. The first test (21-24) on this type were made as before, without air being admitted to the valve. Again visual observations as before indicated apparent improved flow conditions over the flush flat bottom. The coefficients were erratic but were slightly lower than those obtained under the same conditions with the flush flat bottom. The graphical comparison of these coefficients is shown on figure 7.

Tests 25-28 employing the recessed bottom, but with the admission of air, were also quite satisfactory by the visual tests. The data obtained from the tests also verified previous results. Although the range of coefficients was slightly greater than with the flush flat bottom they were still quite constant for each valve opening at the various heads as tested. The effect of the admission of atmospheric air to the stream flow is shown graphically in figure 8.

Further visual tests were run under various conditions to



EXPLANATION

□ 20' Head △ 10' Head
× 15' Head ○ 5' Head
——— Double bowl
- - - - 40° Single bowl

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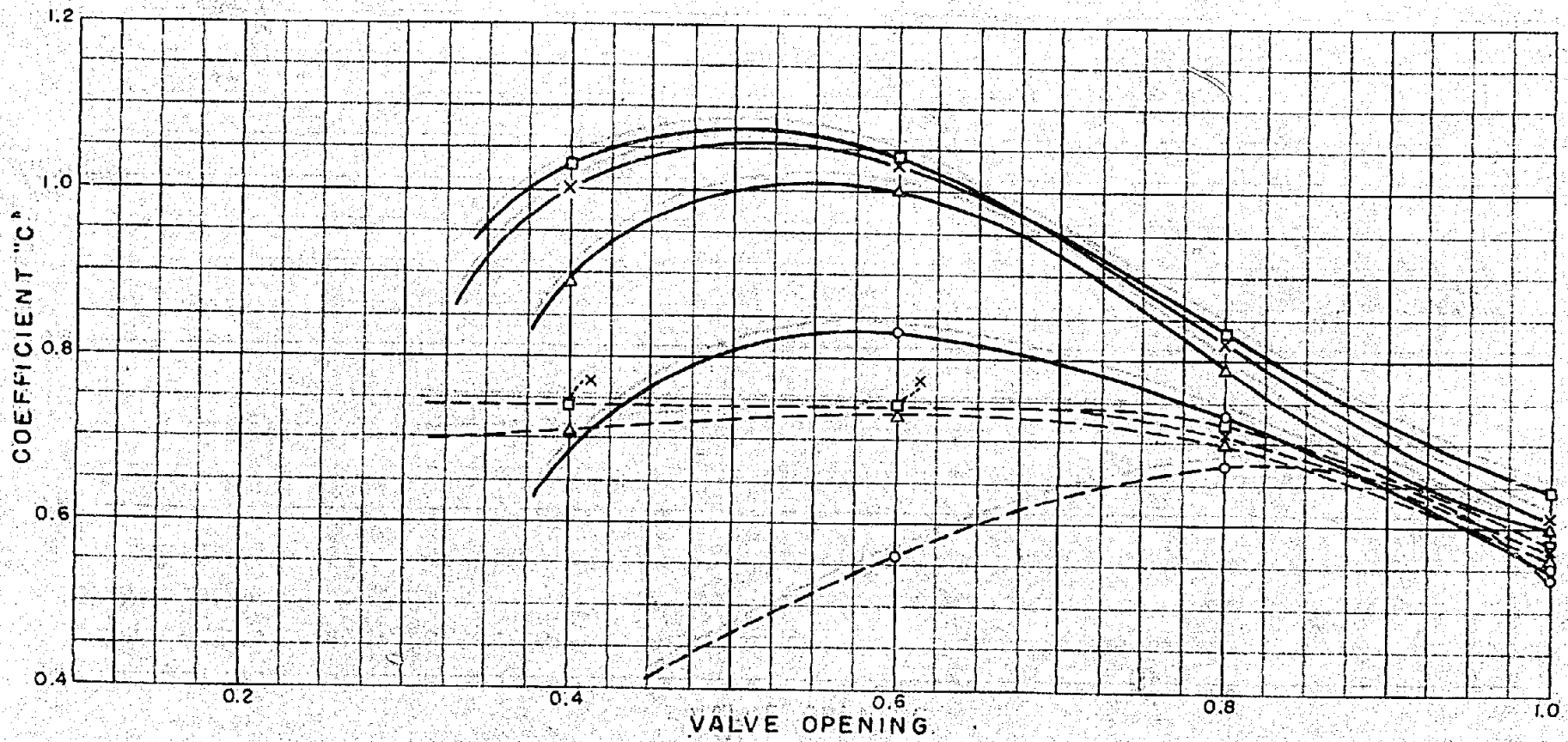
ENERGY ABSORBER
GRAPHICAL COMPARISON
OF DISCHARGE COEFFICIENTS
IN TWO TYPES OF RECEIVERS
FLUSH FLAT BOTTOM
WITH AIR ADMITTED

FIGURE 5



EXPLANATION

□ 20' Head △ 10' Head
x 15' Head ○ 5' Head
——— No air admitted
- - - - Air admitted

ENERGY ABSORBER
GRAPHICAL COMPARISON
OF DISCHARGE COEFFICIENTS
40° SINGLE BOWL RECEIVER
FLUSH FLAT BOTTOM

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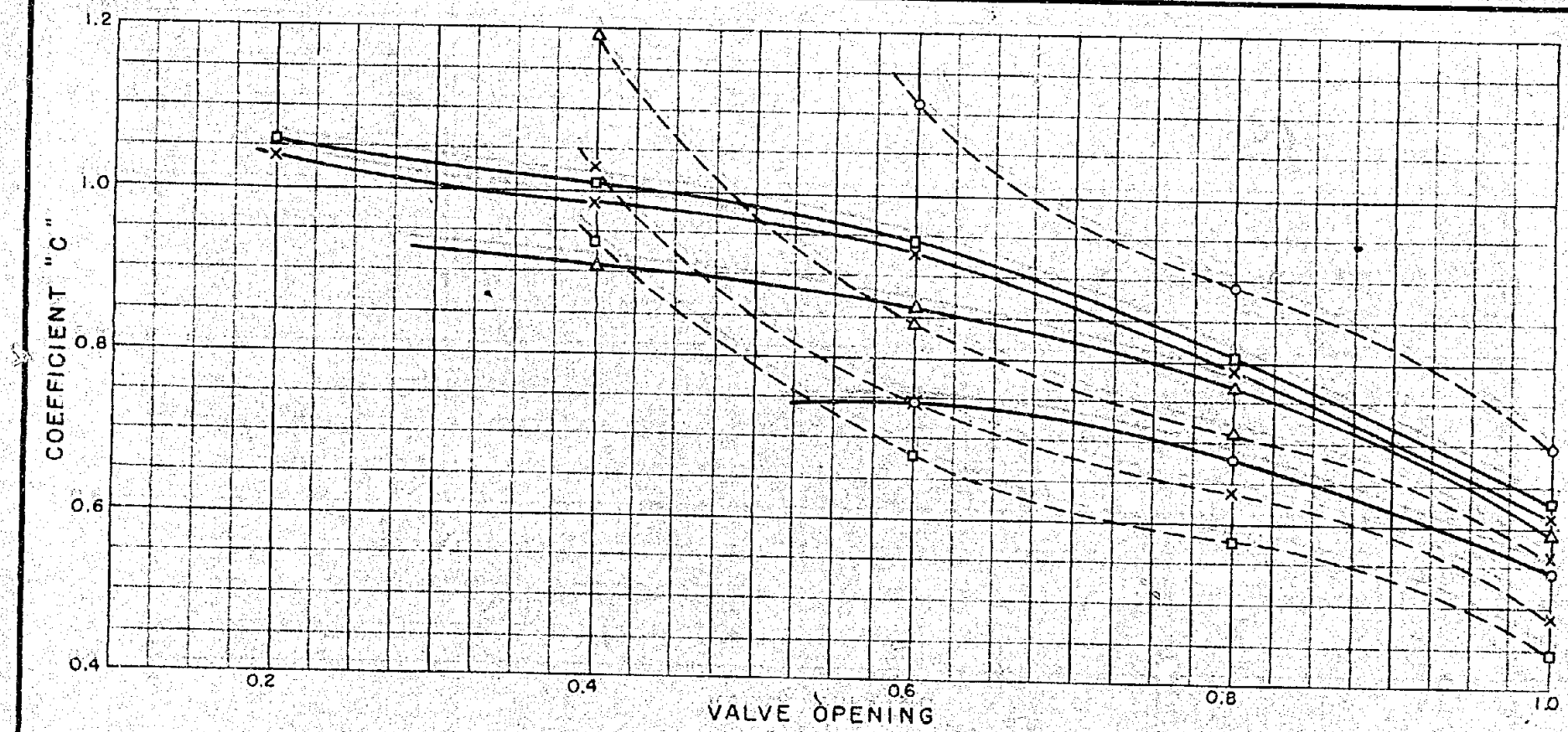
FIGURE 9



EXPLANATION

□ 20' Head △ 10' Head
× 15' Head ○ 5' Head
——— Double bowl
- - - - 40° Single bowl

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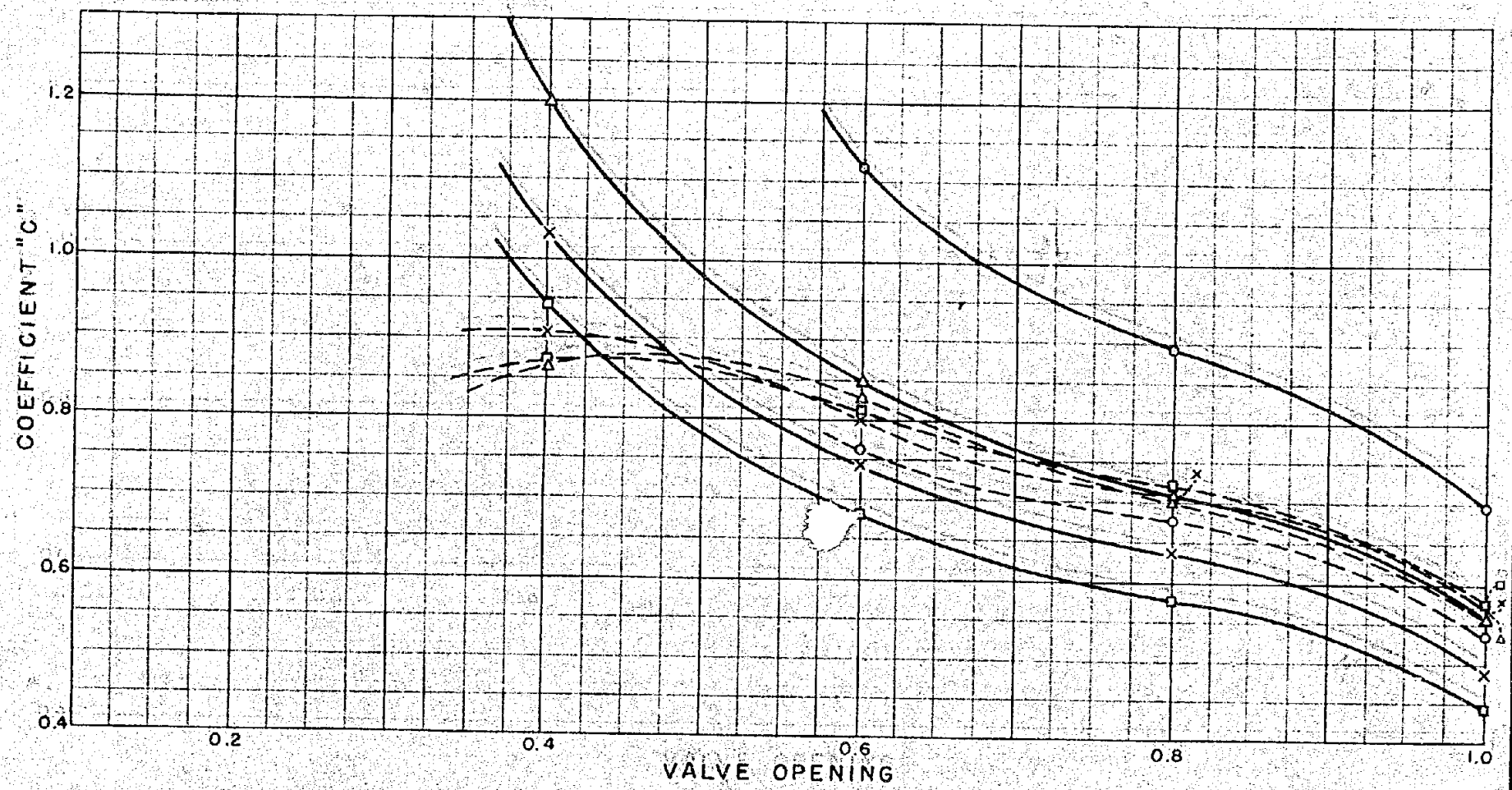
ENERGY ABSORBER
GRAPHICAL COMPARISON
OF DISCHARGE COEFFICIENTS
IN TWO TYPES OF RECEIVERS
RECESSED BOTTOM
WITH NO AIR ADMITTED

FIGURE 7



EXPLANATION

□ 20' Head △ 10' Head
x 15' Head ○ 5' Head
——— No air admitted
- - - - Air admitted

ENERGY ABSORBER
GRAPHICAL COMPARISON
OF DISCHARGE COEFFICIENTS
40° SINGLE BOWL RECEIVER
RECESSED BOTTOM

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FIGURE 8

determine if any obvious defects were apparent and it was found that the flow from the valve seat was slightly irregular, evidently due to the design of the interior of the valve body. The model was dismantled and a change made in the valve chamber and another set of data obtained.

9. Tests 29-44 - 40-degree single-bowl receiver with corrected valve body. As before, the 40-degree single-bowl receiver was tested with the two lengths of vertical discharge chambers. The flush flat-bottom type was tested first (tests 29-32) with no air being admitted to the valve. Under the same operating conditions that existed before the valve body correction, the discharge was slightly increased, (table 2 and figure 7). This also tended to increase the discharge coefficient, but as before, the variance was still too great, although the difference was quite small for a change in head on each valve opening. These values have been plotted on figure 10. Visually, practically the same conditions of cavitation, vibration, and flow existed below the valve seat.

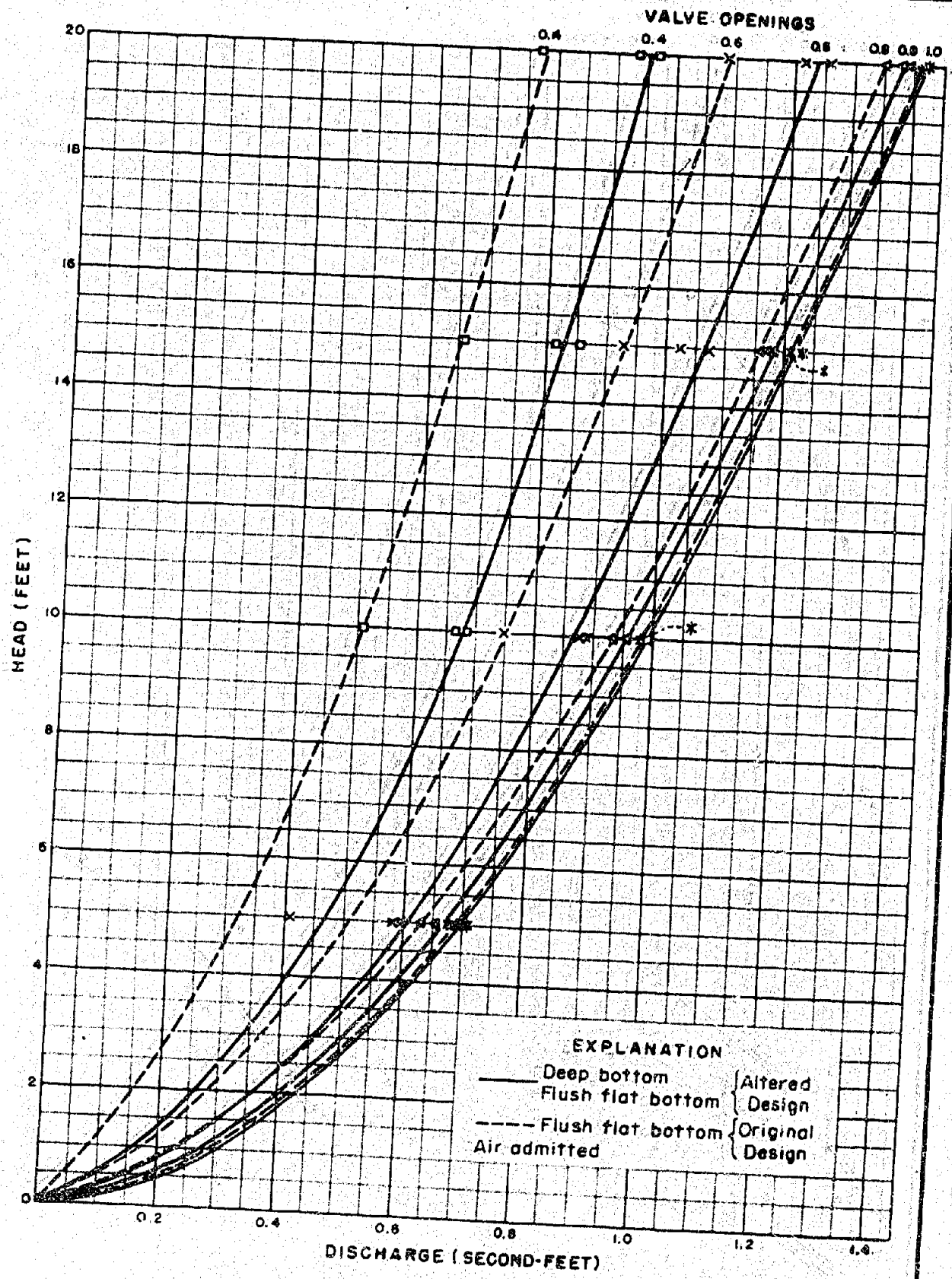
The flush flat-bottom type was next tested (tests 33-36), with air being admitted to the valve and under the same operating conditions as before. Here the discharge was appreciably increased as shown on figure 9. The discharge coefficient was increased, reaching a maximum of 0.92, but varying down to 0.55 due to a change in head. This variance is not of so much importance when the data are examined and practically the same coefficient found for each valve opening irrespective of the head. These values are plotted on figure 10 and it will be noted for the first time that it is possible to define these values by one line whereas before it has been necessary to use four lines. Visually the

ENERGY ABSORBER TEST DATA

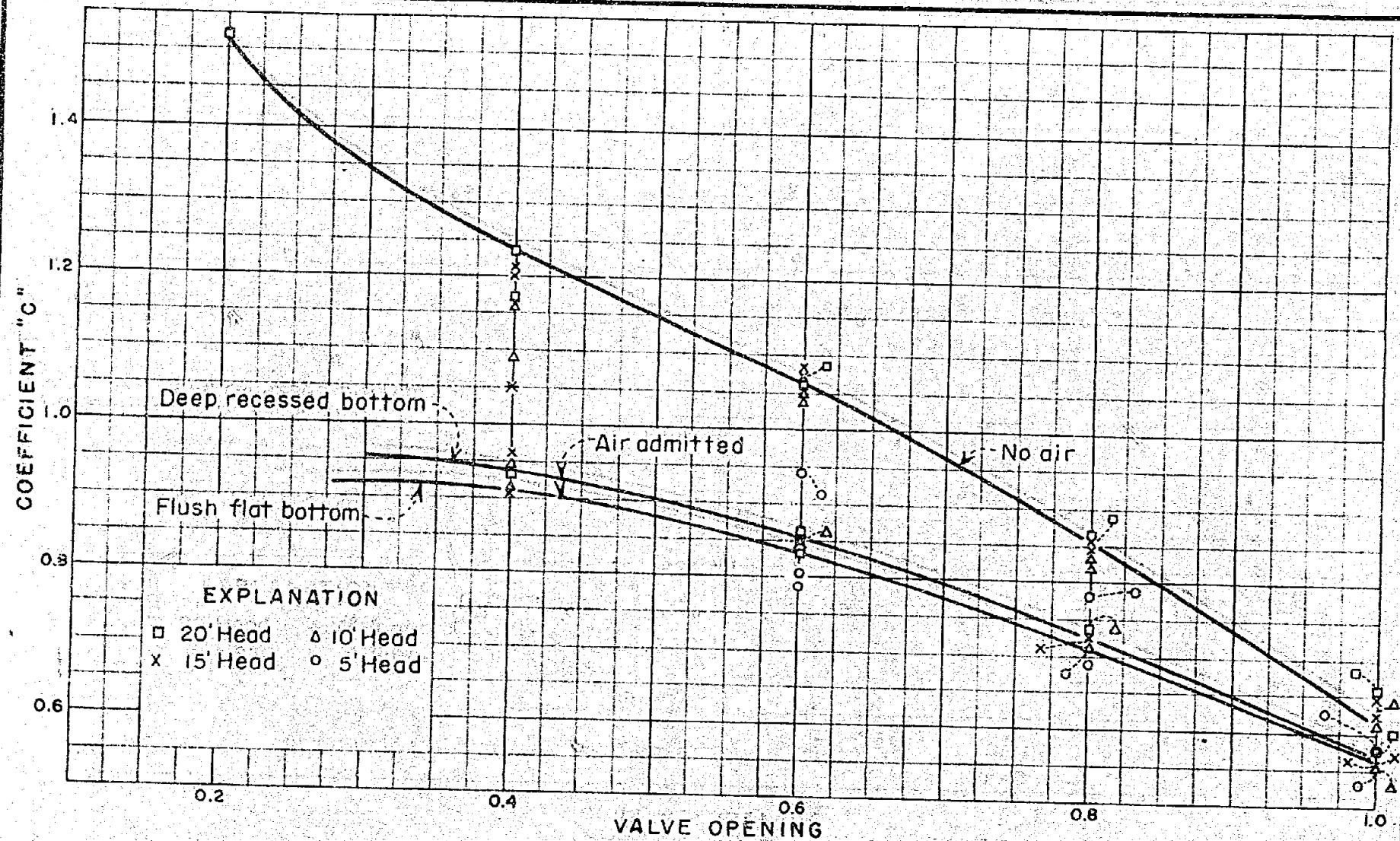
TEST No.			29-32		33-36		37-40		41-44		45-48		49-52	
RUN No.	STATIC HEAD FEET	VALVE OPEN-ING	FLUSH FLAT BOTTOM				RECESSED BOTTOM				FLUSH FLAT BOTTOM			
			NO AIR		AIR		NO AIR		AIR		NO AIR		AIR	
			Q	C	Q	C	Q	C	Q	C	Q	C	Q	C
1	20	.2	—	—	—	—	0.67	1.36	—	—	0.69	1.38	0.58	1.17
2		.4	1.21	1.17	0.94	0.91	1.27	1.23	0.96	0.93	1.19	1.16	0.95	0.93
3		.6	1.56	1.07	1.22	0.83	1.55	1.06	1.26	0.86	1.56	1.07	1.22	0.83
4		.8	1.63	0.86	1.38	0.73	1.63	0.86	1.39	0.74	1.64	0.87	1.36	0.72
5		1.0	1.62	0.66	1.42	0.58	1.62	0.66	1.43	0.58	1.64	0.66	1.44	0.58
1	15	.2	—	—	—	—	—	—	—	—	0.57	1.32	0.51	1.18
2		.4	1.08	1.21	0.81	0.91	1.07	1.20	0.85	0.96	1.06	1.19	0.83	0.93
3		.6	1.36	1.08	1.02	0.81	1.36	1.07	1.07	0.85	1.36	1.07	1.04	0.82
4		.8	1.39	0.85	1.18	0.72	1.40	0.86	1.18	0.72	1.36	0.83	1.17	0.71
5		1.0	1.38	0.65	1.22	0.57	1.33	0.62	1.23	0.58	1.35	0.63	1.21	0.56
1	10	.2	—	—	—	—	—	—	—	—	0.45	1.29	0.39	1.11
2		.4	0.84	1.16	0.67	0.92	0.79	1.09	0.69	0.94	0.83	1.14	0.68	0.94
3		.6	1.09	1.05	0.88	0.85	1.08	1.04	0.88	0.85	1.10	1.06	0.85	0.82
4		.8	1.11	0.83	0.99	0.74	1.10	0.82	0.95	0.71	1.10	0.82	0.95	0.71
5		1.0	1.10	0.63	0.98	0.56	1.07	0.61	0.98	0.56	1.07	0.61	0.99	0.57
1	5	.2	—	—	—	—	—	—	—	—	—	—	—	—
2		.4	0.54	1.05	—	—	0.47	0.92	—	—	0.53	1.03	0.44	0.85
3		.6	0.69	0.94	0.59	0.80	0.70	0.94	0.59	0.80	0.75	1.02	0.60	0.81
4		.8	0.74	0.78	0.67	0.71	0.73	0.78	0.66	0.69	0.71	0.75	0.64	0.68
5		1.0	0.69	0.56	0.68	0.55	0.71	0.58	0.69	0.56	0.72	0.58	0.70	0.57

TABLE 2

FIGURE 9



COMPARISON OF CHANGE IN DISCHARGE CURVES
DUE TO DESIGN OF VALVE BODY



ENERGY ABSORBER
GRAPHICAL COMPARISON
OF DISCHARGE COEFFICIENTS
40° SINGLE BOWL RECEIVER

H.D.B. 6-21-39

FIGURE 10

flow within the chamber was smooth and regular and there was no evidence of the "noise of cavitation" when sufficient air was allowed to enter the valve chamber. The noticeable "surging flow" had also been practically eliminated.

The recessed bottom was also tested without air (tests 37-40) and the discharge again found to agree with the values found for tests 29-32. The coefficients were of course of practically the same value and are shown graphically on figure 10, being represented by the same line.

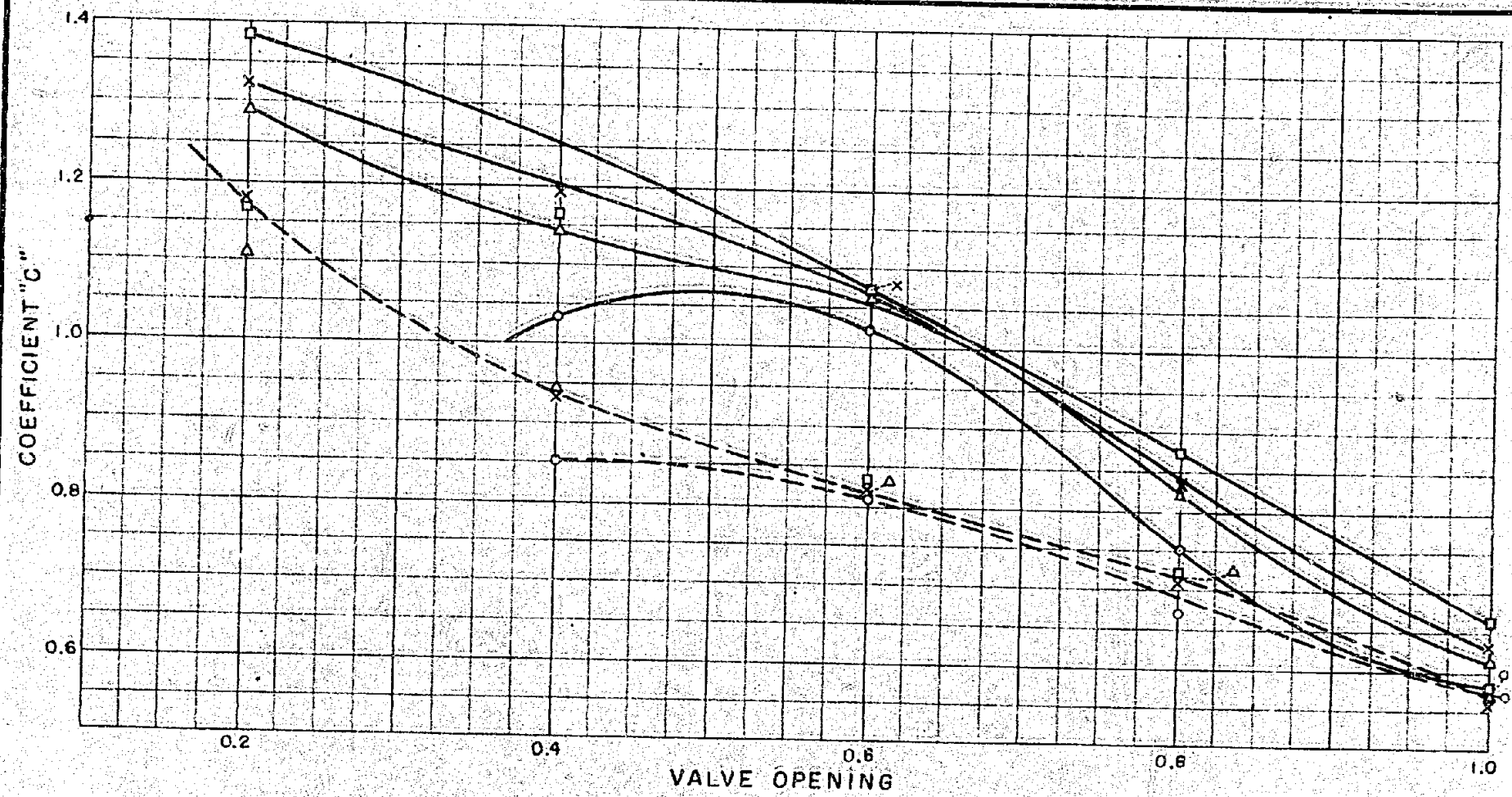
The last test (41-44) was made on the recessed bottom with air being admitted through the valve body. The discharge was found to have increased slightly over the tests on the flush flat bottom under the same operating conditions and to have increased considerably over the original valve design when the same conditions of discharge existed. The discharge coefficient was increased slightly over the flush flat-bottom type (figure 10). The coefficients under the various heads were practically identical for the same valve opening, in fact, they are represented on the figure as one line. Visually the test appeared to practically fulfill the criteria as set up but with one construction question; namely, "Is the improved coefficient and flow characteristic of the recessed-bottom type economically worth the increased excavation and construction cost over the flush flat-bottom type?" Naturally no specific economic value can be placed on either type so as to determine whether or not it would be possible to maintain approximately the same values and conditions of flow as

found in the recessed-bottom type by using the same type of bottom but moving it up into the flush position was suggested and a full set of tests were run with the curved bottom in this position.

FINAL STUDIES

10. Tests 45-52 - Curved bottom flush with bottom of discharge passage. This type was also tested without air being admitted to the valve and the data are shown on table 2 (tests 45-48). Graphically these data are shown on figure 11 and show, as did tests 37-40, a slight increase in both discharge and coefficient over the tests on the flush flat-bottom type. With these favorable data, further tests were run under the same conditions with air being admitted at the valve (tests 49-52). The measured discharge and coefficients are shown on table 2, while on figure 11 these values are again represented by a single line which, it will be noted, falls almost midway of the two lines on figure 10 which represent identical conditions but with different types of bottoms. Previous tests had indicated that it might be possible to design a type which would function almost as effectively as the deep recessed bottom and even better than the flush flat-bottom type, and these tests carried out those convictions giving very constant results with the exception of the low head which is a rare case and can be neglected. Also due to some unknown inequality, these two points may be in error although they were checked both numerically and on the model.

Visually this type appeared as good, if not better than the recessed-bottom type; that is, the air and water seemed well mixed



EXPLANATION

□ 20' Head Δ 10' Head
X 15' Head ○ 5' Head
——— No air admitted
- - - - Air admitted

H.D.B. 7-14-39

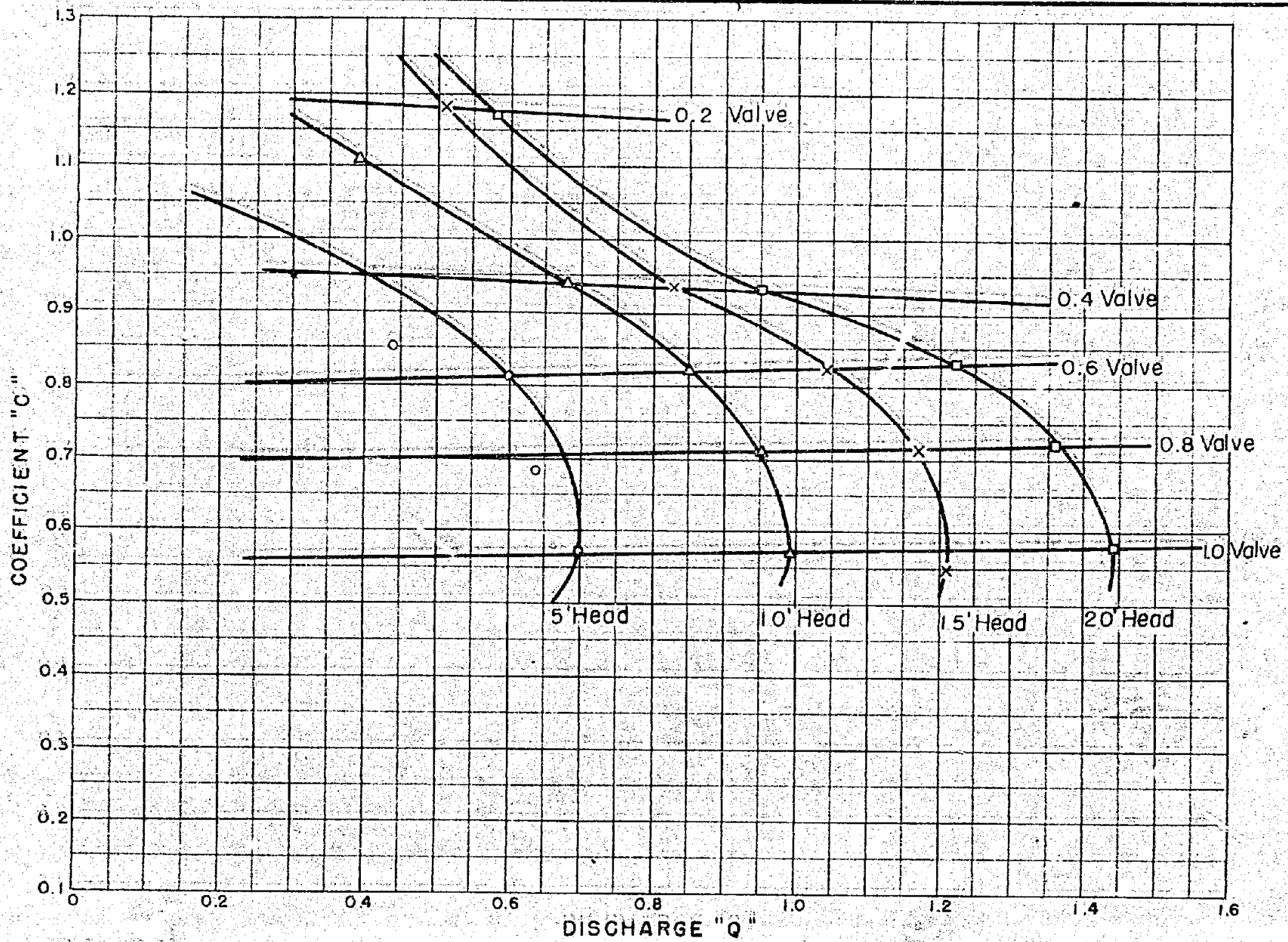
ENERGY ABSORBER
GRAPHICAL COMPARISON
OF DISCHARGE COEFFICIENTS
40° SINGLE BOWL RECEIVER
CURVED FLUSH BOTTOM

FIGURE 11

within the receiver bowl while the flow through the discharge passage was uniform, of a low velocity, and was well distributed throughout the tube. Also, the tailwater was not too visibly agitated due to the escaping air at the mouth of the draft tube.

As a further demonstration of the regularity and consistency of the test results from the model and as an example of just how this data can be made use of for design purposes and possible field operation if the unit is used as a synchronous bypass is shown on figure 12. On this curve sheet the coefficient "C" has been plotted against the discharge "Q". The horizontal lines, which are almost parallel, represent constant coefficients at various valve openings for any given head while the curved lines, which are of the same family, represent the change in discharge due to the coefficient under identical static heads.

To insure a proper design and to fulfill the design criterion as set up in paragraph 1, it is recommended that the unit be made up as follows: (1) The control valve should be of the semiscroll case type with the main valve being controlled by a small inner-contained pilot valve. This valve body should also be provided with the air valves of sufficient size as shown on the valve design on figure 2. (2) The receiver bowl should be of the type as shown on figure 2; that is, it should be a single bowl having a flare of 40 degrees with the vertical. (3) The discharge bowl and tube should be sufficiently large so as not to restrict the flow or cause a concentration or increase in the velocity of the discharging water. It is also suggested



H.D.B. 7-27-39

FIGURE 12

that the type as shown on figure 2 be followed quite closely in the design of the discharge passage in order to insure stability both in the unit and in the flow.

From and upon the visual tests and the actual test data as presented and elaborated upon, it is believed that a suitable energy absorber has been developed for installation in connection with large turbines operating under high heads.
