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A LABORATORY EVALUATION OF TRASH RACKS FOR DROP INLETS
HEBAUS, G.G.; GWINN, W.R. 1 OF 1

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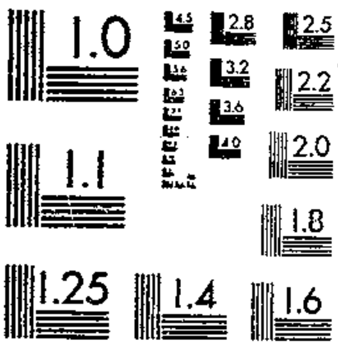

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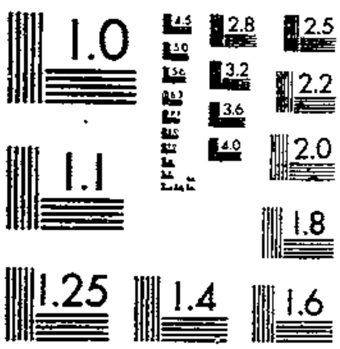

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A LABORATORY EVALUATION OF TRASH RACKS FOR DROP INLETS

Technical Bulletin No. 1506

Agricultural Research Service
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CONTENTS

Page
Acknowledgments ii
Summary 1
Introduction 1
Measures of trash-rack effectiveness 1
Trash racks tested 2
Test apparatus 2
Trash specimens and standard trash loads 4
  Standard flexible-trash load 5
  Standard rigid-trash load 6
Test procedure 6
  Flexible-trash tests on full-size structures 6
  Flexible-trash tests on small models 6
  Rigid-trash tests on small models and full-size structures 7
Test results 7
  The four-way square drop inlet 8
    The full-size structure tests 8
    The model tests 9
  The hillside inlet 13
  The two-way drop inlet 19
    The clear water tests 19
    The trash tests 25
The Soil Conservation Service standard trash racks 38
  Racks 1 and 1 (high) 38
  Racks 2 and 2a 41
  Racks 3, 3a, and 3b 44
  Rack 4 52
  Rack 5 52
Relative performance of trash racks 55
  Performance under flexible-trash loads 55
    Weir flow 55
    Pipe flow 60
  Performance under rigid-trash loads 61
    Weir flow 61
    Pipe flow 62
Model-prototype similarity 62
Similarity of laboratory tests to field conditions 63
Comparison of flexible- and rigid-trash flows 65
Trash-rack maintenance 65
Significant findings 67
Recommendations 67
Appendix.—The movement of trash in a reservoir 68

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A LABORATORY EVALUATION OF TRASH RACKS FOR DROP INLETS

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SUMMARY

Performance tests for trash racks on closed-conduit spillways, using one-eighth-scale models, were developed and standardized by comparison with the performance of full-scale prototype structures mounted on a drop inlet to a 2-foot-diameter conduit.

Flow data for use in spillway design were collected by testing models and prototypes of standard and experimental designs under a range of flow conditions, with clear water and standardized trash loads.

INTRODUCTION

An entrance trash rack is normally required to prevent plugging of closed-conduit spillways that release water from floodwater-retarding reservoirs. The effectiveness of the trash rack is highly dependent on its geometry. It is possible for the trash rack itself to become so plugged with trash that a reduction in spillway capacity results. A rack form that intercepts trash with minimum reduction of flow through the spillway is therefore needed. Various forms of trash racks, including Soil Conservation Service (SCS) standard designs, were studied in laboratory experiments at the Water Conservation Structures Laboratory at Stillwater, Okla., to determine how well they met this need. The results of these studies are presented here for the guidance of designers of flood-control works.

The trash racks were tested on both model- and prototype-size structures. Their performance was evaluated by comparing the weir and entrance loss coefficients for trash-laden flows with the corresponding values for clear water flows. The tests were intended to indicate (1) how well a given trash rack would perform its function, (2) the relative performance of the trash racks, and (3) the reliability of models for trash-rack research.

MEASURES OF TRASH-RACK EFFECTIVENESS

The effectiveness of a trash rack is judged by its ability to preserve the clean flow capacity of the structure as trash accumulates on the rack. A measure of flow capacity is the change in the value of the weir-flow discharge coefficient, the plate-control discharge coefficient where applicable, or the pipe-flow entrance-loss coefficient.

The weir-flow discharge coefficient, C, is defined by the relation

$$C=\frac{Q}{LH^{3/2}}, \qquad (1)$$

where Q=the discharge in cubic feet per second,
L=the crest length of the weir in feet,
and H=the head above the crest in feet.

A decrease in this coefficient indicates a reduction in flow capacity of the structure.

The plate-control coefficient, C_p, is defined by the relation

$$C_p=\frac{Q}{\alpha H-b}, \qquad (2)$$

where C_p=plate-control coefficient,
Q =discharge rate in cubic feet per second,

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and H = head referred to spillway crest in feet.

a and b are determined by the dimensions of the inlet and are obtained by the solution of the equation for plate control. A decrease in C_p indicates a reduction in the flow capacity.

Donnelly, Hebaus, and Blaisdell[2] have developed the following equation for plate control:

$$\frac{H}{D} = \frac{Z_P}{D} - \left\langle \frac{0.2}{L/D} - 0.1 \log_{10} \frac{L_o}{D} \right\rangle + \left\langle 0.1 - \frac{0.05 L_o}{D} \right\rangle$$

$$\frac{Q}{2LD^{3/2}} \geqq \frac{Z_P}{D}, \qquad (3)$$

where D = width of drop inlet,
L = length of drop inlet,
and L_o = overhang of the plate beyond the outside of the drop inlet.[3]

The quantities in pointed brackets are zero for negative values.

The pipe-flow crest-loss coefficient, K_c, is defined by the relation

$$K_c = \frac{\Delta h - h_{vr}}{h_{vr}}, \qquad (4)$$

where Δh is the pressure drop between the water surface above the entrance to the structure and the drop inlet midheight in feet, and h_{vr} is the mean velocity head in the drop inlet in feet. An increase in the pipe-flow crest-loss coefficient indicates a reduction in the flow capacity of the structure.

The crest-loss coefficient is based on the velocity head in the drop inlet. Coefficients used by designers are, for convenience, often based on the velocity head in the barrel.

To express the crest-loss coefficient in terms of barrel velocity head, h_{vp}, K_c can be multiplied by the square of the ratio of the barrel area to the drop inlet area, $\left(\frac{A_p}{A_r}\right)^2$.

Thus $$K_c \left(\frac{A_p}{A_r}\right)^2 = \frac{\Delta h - h_{vr}}{h_{vp}}.$$

TRASH RACKS TESTED

The trash racks tested included early (circa 1948) and current (1969) designs used by the Soil Conservation Service on drop inlets during the time the tests were made, 1957 to 1969. Some modifications to these designs were also tested.

Table 1 lists the trash racks and the tests to which they were subjected. By "model" is meant a reduced-scale structure placed in an indoor hydraulic-laboratory testing flume. A "prototype" is a large-scale test structure (with barrel diameter of 2 feet) placed in an outdoor test basin. "Flexible trash" is hay for the prototype and simulated hay for the model. "Rigid trash" is sticks and small logs for the prototype and twigs and small sticks for the model. Drawings of the racks tested are included in this bulletin.

TEST APPARATUS

In this research, both reduced-scale and full-size models (termed "model" and "prototype," respectively) of drop inlets and trash racks were tested. Since model tests are much faster and less expensive than prototype tests, an important part of the research was directed toward development of test techniques that would yield model-test data closely simulating prototype performance during trash-laden flow. With such techniques available, it will be possible to carry on much of the future trash-rack research with models only.

The full-size structures had a 2-foot-diameter concrete outlet pipe with a fall of approximately 11 feet. They were located in an approximately square reservoir having a surface area of about one-half acre when full. Flow into the reservoir was measured with a 4-foot modified Parshall flume. The water level in the reservoir and the pressures in the test structure for the first tests

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[2] Donnelly, Charles A., Hebaus, George G., and Blaisdell, Fred W. 1974. Hydraulics of closed conduit spillways. Part XII. The two-way drop inlet with a flat bottom. U.S. Dep. Agric., Agric. Res. Serv. [Rep.] ARS-NC-14.

[3] The definition for L_o by Donnelly, Hebaus, and Blaisdell has been used here. Elsewhere in this report L_o is defined as the distance between the outside of the drop inlet wall and the inside of the skirt. The two values of L_o obtained by applying the two definitions to a structure differ by the thickness of the skirt.

TABLE 1.—*Test combinations of structures, trash racks, and test conditions*

Structure	Trash-rack designation[1]	Figure number[2]	Laboratory tests: Flexible trash, Model	Laboratory tests: Flexible trash, Prototype	Laboratory tests: Rigid trash, Model	Laboratory tests: Rigid trash, Prototype	Design[3]	Laboratory modifications and variations tested	Remarks
4-way square drop inlet.	...	9	x	x	...	...	S	None	Trash rack no longer being built. Various trash materials, loads, and feeding rates applied in model to simulate prototype behavior.
Hillside inlet	...	19	x	...	...	...	S	None	Model of prototype structure #16 on Sandstone Creek, Okla.
2-way drop inlet	...	23	x	...	...	...	L	Inlet lengths, $2D$ and $3D$; deck heights, $(1/2)D$ and D; deck overhang, D and $(3/2)D$; solid and vented decks; combinations of solid and vented side skirts; round bar, spacing $(1/3)D$ and $(4/9)D$.	Standard flexible-trash test applied to all variations. One test conducted without bars.
3-way square drop inlet.	1	38	...	...	x	x	S	None	Standard rigid-trash test designed in prototype and duplicated in model.
Do.	1 (high)	38	x	...	...	...	S	High rack and inlet in dam face.	No prototype.
Do.	2	44	...	...	x	x	L	Vented skirt on part of sides.	Rack moved farther from inlet than in rack 1.
Do.	2a	44	x	x	x	x	L	Vented skirt on all of sides	Do.
2-way drop inlet	3	52	x	...	x	x	S	None	Splitter wall omitted in most tests.
Do.	3a	52	...	...	x	x	M	Vented skirt on part of sides.	Splitter wall omitted.
Do.	3b	52	...	...	x	x	M	Vented skirt on all of sides	Do.
Do.	4	64	...	...	x	x	L	Minimum-size solid deck used.	...
Do.	5	68	x	...	x	x	S	None	...

[1] Entries in this column refer to the last series of tests, covering standard and modified SCS designs.
[2] Numbers refer to illustrations in this bulletin.
[3] S=standard SCS design; L=laboratory design; M=modified SCS design.

were measured in stilling wells with point gages read to the nearest 0.001 foot. In later tests on the two-way drop inlet, pressures were read directly to the nearest 0.01 foot with small open-tube manometers.

The small-scale models, with one exception, were one-eighth the size of the full-size structures and were made of transparent Plexiglas. The outlet conduit was arranged so that its discharge end could be raised or lowered to alter the head on the system, and, thereby, the pipe-flow capacity of the models. The trash-rack bars were made of brass, and the gratings used for the vented deck and skirts were hardware cloth.

The models were installed in a tank 5 feet 7-1/2 inches wide 2 feet 6 inches deep, and 13 feet 2-1/2 inches long. Flow entered the tank through a 1-foot H-flume, where it was measured, and approached the models very uniformly through a baffle system at the head of the tank. Headwater and pressure measurements were made in stilling wells with point gages read to the nearest 0.001 foot.

Piezometers were placed at the midheight of the drop inlet. In the square drop inlets, a piezometer was located in the center of each wall. In the rectangular, two-way drop inlets, six piezometers were used. One was placed at the midpoint of each upstream and downstream end wall, and two were placed on each side wall, spaced one-third of the drop inlet length from the end walls.

TRASH SPECIMENS AND STANDARD TRASH LOADS

Selection of material for the standard trash loads was based on data derived from an analysis of trash found around 37 flood-detention reservoirs distributed through Oklahoma. In trash on the racks themselves (figs. 1 and 2) and around reservoir shorelines (figs. 3 and 4) were logs of diameters up to 4 inches and lengths up to about 8 to 10 feet; sticks of various diameters, lengths, and shapes; twigs; weed stalks and thistle plants; leaves; livestock manure; and fine materials consisting of decayed grass stems, decayed twigs, and silt. Logs larger than 5 inches in diameter were found on the shore, but not in the trash racks.

The trash was classified as either flexible or rigid. These terms describe the action of trash when it accumulates on a trash rack.

Flexible trash such as hay can wrap around rack members or around other trash lodged against the rack. Rigid trash, represented by sticks and logs, while deformed very little by flow, can accumulate, entangle, and wedge around and in the trash rack. Because of the different behavior of these two kinds of trash, each was tried separately in the trash-rack tests.

Trash specimens for the models had to duplicate the action of the trash in the prototype. Also required was a standard trash test that could be applied to all trash racks so their relative effectiveness could be compared. The first experi-

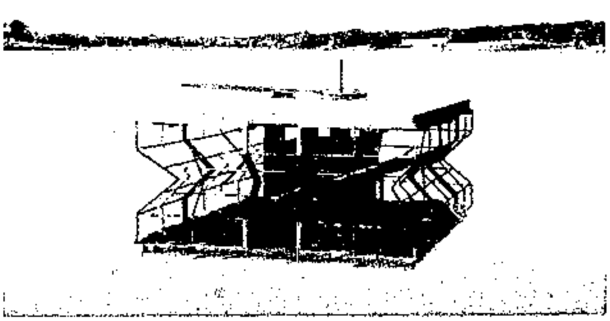

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FIGURE 1.—Open trash rack with log wedged in rack, site 6, Bear, Fall, and Coon Creeks watershed, Oklahoma.

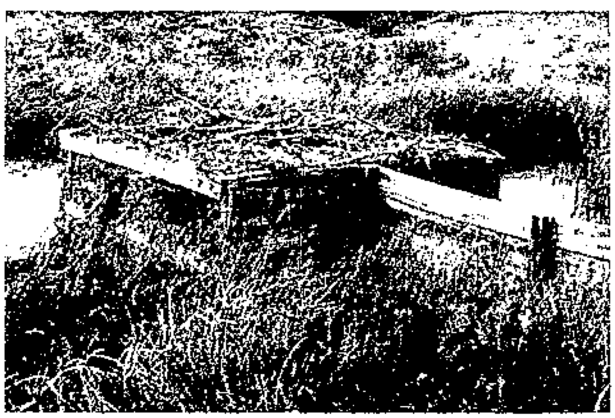

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FIGURE 2.—Woven wire trash rack almost completely plugged, below site 17, Sandstone Creek watershed, Oklahoma.

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FIGURE 3.—Trash pile on face of dam, site 11, Long Branch Creek watershed, Oklahoma.

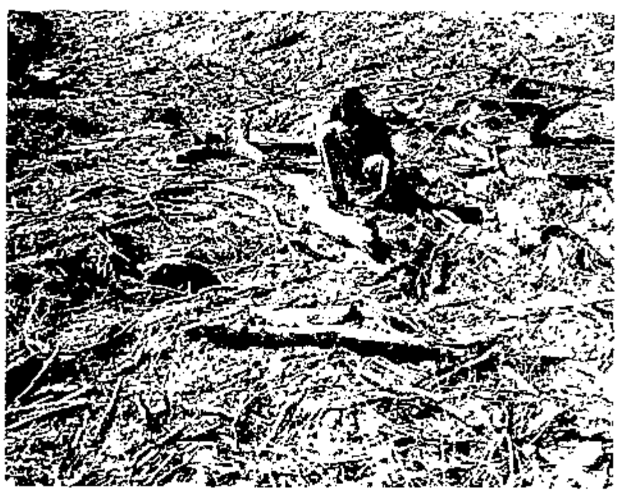

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FIGURE 4.—Trash pile along shoreline, site 6, Turkey Creek watershed, Oklahoma.

ments were devoted to finding a suitable model trash and developing a standard trash test.

Standard Flexible-Trash Load

Hay was selected as the flexible trash for prototype testing. Eight pickup truckloads of loose, dry, weeping lovegrass hay were fed into the reservoir (fig. 5). Much of this material became waterlogged and submerged during the test. Since the same action had to be duplicated in the model, a suitable model material was sought. Grass clippings were tried, but they would not sink. Hemp rope cut into 1-3/4-inch lengths, separated into individual strands (fig. 6) and treated with a weak solution of sulfuric acid to remove grease submerged in the model flow and closely simulated the action of the hay in the prototype.

A standard flexible-trash load of 1,000 grams of air-dry hemp strands, applied at the rate of 40

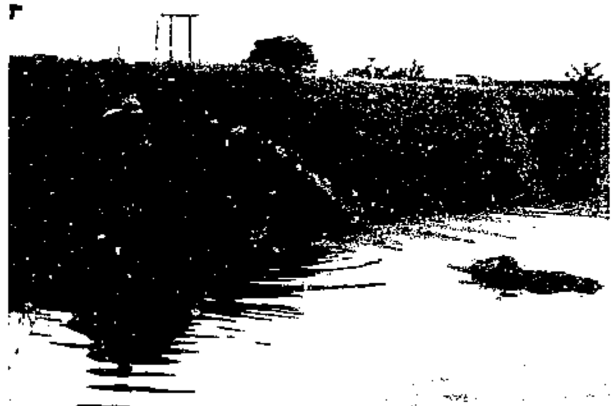

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FIGURE 5.—The flexible-trash specimens used in the prototype tests.

PN—3609
FIGURE 6.—The flexible-trash specimens used in the model tests.

grams every 5 minutes, was used in all flexible-trash model tests after the early development trials.

Standard Rigid-Trash Load

Rigid-trash tests were also conducted, first on the prototype with a three-way drop inlet and later on a model. Fairly straight, smooth logs ranging from 2-1/4 to 5 inches in diameter and from 2 to 17-3/4 feet long and sticks ranging from 1-1/2 to 7-2/3 feet long were used. Six logs and 12 sticks in each of 8 subloads, for a total of 48 logs and 96 sticks in all, were selected as the standard rigid-trash load. Figure 7 shows the random shape and size of the pieces in a typical prototype subload. The same number of pieces, scaled down to one-eighth size, was used for the small-model test.

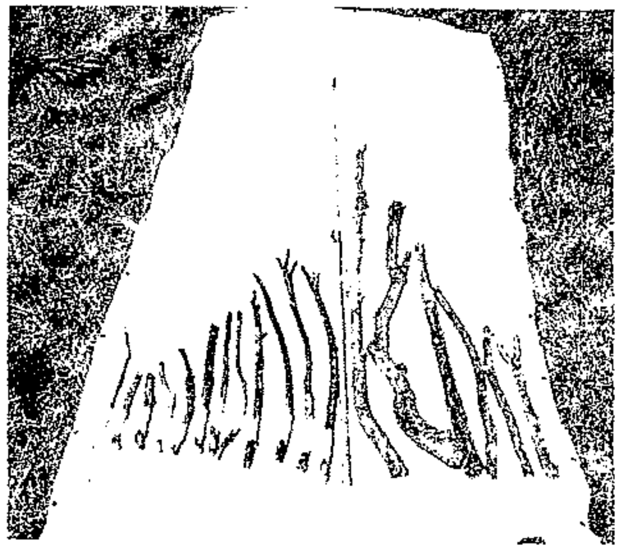

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FIGURE 7.--A typical prototype rigid-trash subload.

TEST PROCEDURE

Each rack was first tested without trash in the flow. The discharge and loss coefficients obtained from these clear water tests provided the basis for assessing the performance of the rack when the flow was charged with trash. The clear water tests on the rack-equipped drop inlet were also compared with clear water tests on the drop inlet without a trash rack, to obtain a measure of the energy loss caused by the rack alone.

Flexible-Trash Tests on Full-Size Structures

Flexible-trash tests were conducted on only two full-size structures, the four-way square drop inlet and the three-way square drop inlet with trash rack 2.

The first trash-rack tests were made on the full-size, four-way square drop inlet. At the beginning there was some exploring and trying out to do, so early tests do not conform to the procedures later adopted as standard. For the first test a flow of 25.4 cubic feet per second (weir-flow range) was introduced into the reservoir. When the flow became steady, the eight pickup truckloads of dry weeping lovegrass hay were fed into the reservoir over a period of 160 minutes.

The inflow rate was increased to 33.6 cubic feet per second, a rate sufficient to cause pipe flow, and the pool level began to rise. This inflow rate was maintained for 22 hours, but equilibrium was not established. The water level in the reservoir was rising at a rate of about 0.06 foot per hour at the end of this prolonged flow.

After the 22-hour pipe-flow run, the inflow rate was reduced to 26.1 cubic feet per second, approximately the same rate used at the start of the test. The water level in the reservoir then began to fall and reached a steady level in 18 hours. Inflow was cut off, and the water drained down to the spillway crest level.

During the run, measurements were made of the inflow rate and the elevation of the water surface in the reservoir. Except for the two weir flows that were at a steady pool level, the measurements were made with a slowly changing reservoir water level for the test on the four-way square drop inlet. For trash rack 2a the measurements in the weir-flow range were for steady flow.

Flexible-Trash Tests on Small Models

The standard flexible-trash load for the small models was introduced into the flow over a 125-minute period which began after pipe flow was established. By this procedure, data for calculation of the weir and crest-loss coefficients for clear water flow were obtained during the initial part of the trash test, without having to run a separate clear water test.

During the initial part of the test, the clear water flow into the model basin was increased by steps. Water level and inflow rate were measured when the water level became constant after each flow increase. After the flow rate reached the pipe-flow range, one final set of clear water flow measurements was made. Then the inflow was increased slightly, and as the water level in the basin rose, trash feeding was begun. After feeding was complete, the water usually reached a level four to five pipe diameters above the weir crest. This level was held constant for about 1 hour by holding inflow rate constant and adjusting the elevation of the outlet pipe. This was enough time for all the trash either to lodge on the rack or to sink to the tank floor. Then, with the inflow rate unchanged, the head pool was lowered by lowering the outlet pipe to increase the effective head. When the head-pool had stabilized, the entrance-head readings and the time of measurement were recorded. After about seven such measurements at successively lower pool levels in the pipe-flow range, the inflow was reduced in steps through the weir-flow range, and flow was allowed to become steady in each step before head measurements were made. After the test, the trash caught on the rack was removed, dried, and weighed.

Rigid-Trash Tests on Small Models and Full-Size Structures

For the rigid-trash tests, in both models and prototypes, the flow was increased in eight steps —three in the weir-flow range, two in a transition range in which the flow could be under plate control, and three in the pipe-flow range. After each flow increase, one rigid-trash subload was fed. Head and discharge measurements were made when the head-pool level became steady (in the full-size structure, steady pipe flow required a long waiting time, so readings were usually taken during unsteady flow and adjusted for storage change). This procedure of feeding trash on the rising stage was intended to stimulate the way trash would reach a structure in a reservoir. After all the trash had been fed, the flow was reduced in seven steps and the measurements were repeated.

This test procedure was used to enable measurement of the effect of trash buildup during the rising stage and its cumulative effect in the falling stage. The number of logs and sticks that passed through the structure, were floating in the reservoir, or were deposited on the banks was recorded. Trash lodged in the rack was photographed and counted. To record how the trash approached the structures, 16-millimeter time-lapse movies were taken during the full-size structure tests.

TEST RESULTS

Under the heading for each type of structure is a description of any test procedure that differed from the standards previously described, the test results, and a discussion of rack performance.

The percentages of total trash loads caught on the rack and passing through the spillway for any given rack are less than 100 percent because the trash floating on the surface, resting on the bottom of the model basin, or left lying on the reservoir shore after each test was not reported.

Water for the model experiments was drawn directly from Lake Carl Blackwell and contained varying amounts of suspended sediment. After all the trash had been fed and had either reached the structure and passed through it, lodged on its rack, or settled to the basin floor, sediment particles from the water continued to accumulate on the flexible-trash fibers lodged on the rack. This resulted in an increase in crest-loss coefficient K_r with time. An example of the increase of K_r is shown in figure 8. There was no cumulative effect from test to test because the trash fibers were washed and dried after each test. During test 59 on the four-way drop inlet, the water was especially muddy, and the trash fibers were much darkened by accumulated sediment.

Since K_r increases with time because sediment accumulates in the trash, values of K_r measured long after the end of trash feeding in the models are not a realistic measure of the effect of trash alone. Therefore, a method for establishing a coefficient unaffected by sediment was developed. Since the increase in K_r with time caused by the

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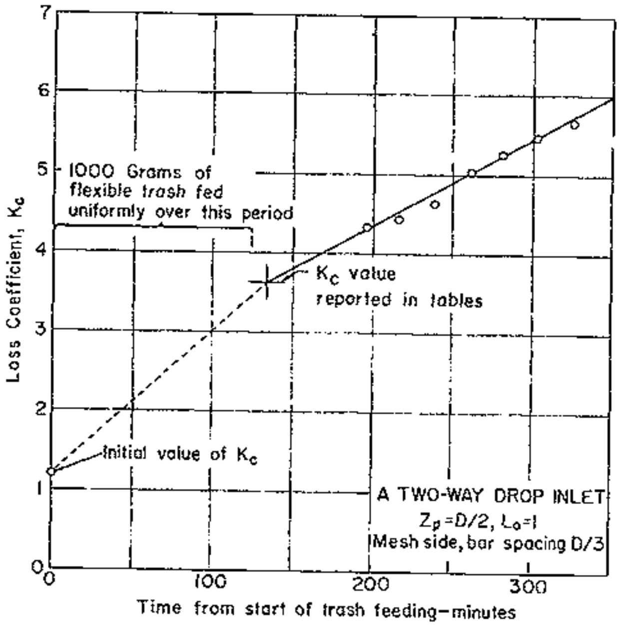

FIGURE 8.—Increase of entrance-loss coefficient with time for a two-way drop inlet during a trash test on a model.

sediment accumulation was apparently linear (fig. 8), the line showing the trend of K_c values was projected back to 135 minutes from the start of feeding. By this time (10 minutes after the end of trash feeding), all trash had either reached the structure or had sunk to the floor. The projected value of K_c at 135 minutes more truly represents the head loss due to trash alone, excluding most of the unwanted effects of suspended sediment. It was, therefore, adopted as the standard value of K_c for evaluating the effect of trash on rack performance. Since weir coefficients for many of the model tests were obtained from flows near the end of the test, they also include the effect of suspended sediment. On the model racks, there is no way to evaluate the effect on the weir coefficient of sediment accumulation on flexible trash. However, the possible presence of this effect should be kept in mind when applying these data to field structures.

The Four-Way Square Drop Inlet

The full-size structure had a concrete drop inlet, with a 24-inch-diameter concrete culvert pipe for the barrel. Rack members were fabricated from 2- by 2- by 1/4-inch structural steel angles, and the decking and skirts were made of 2-inch, full-dimension, rough-sawed lumber. The deck planks were 2 by 6 inches and were spaced one-half inch apart. The test structure closely simulated field structures being built at that time (1956). Figure 9 is a drawing of the test structure. The model drop inlet was one-eighth the size of the full-size structure and was built of transparent Plexiglas. Flexible trash only was used in tests on both the prototype and model of this structure.

The full-size structure tests

Prototype tests were conducted first. The structure was brought into steady weir flow, and eight pickup truck loads of dry weeping lovegrass hay were fed into the upper end of the reservoir. Three hours after the start of feeding, most of the hay was floating near and around the structure. There was very little wind during this test. The inflow was then increased to bring the structure into pipe flow. This flow rate was maintained for 22 hours, during which time much of the hay became waterlogged and sank.

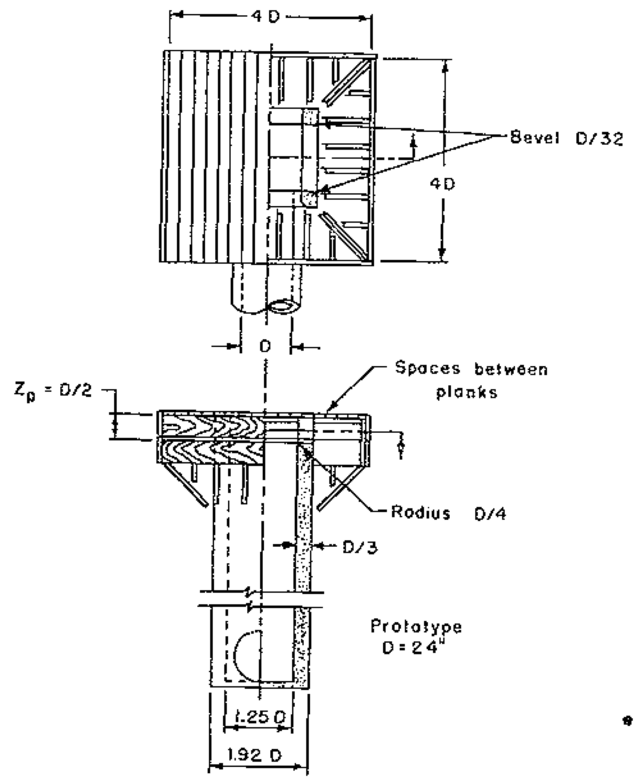

FIGURE 9.—The four-way square drop inlet and trash rack.

The inflow was then stopped. When the head pool was drained, large accumulations of hay on the rack became visible. A net placed around the structure before the test was used to catch the hay that fell of the rack bars (fig. 10). This, combined with the material remaining on the rack, weighed about 47 pounds when dried.

About 2-1/2 weeks later the test was repeated. It was thought probable that the trash deposited around the structure during the previous test, and now dry, would float up with a rising head pool, lodge on the trash rack bars, and produce a test more severe than the first. Instead, the dry hay rose up past the trash-rack bars. The wind was blowing at the time, so hay remained only on the leeward side of the inlet. On the windward side it was blown away. As a result, only about 15 pounds of hay (estimated, not measured) lodged on the rack (fig. 11). The second test, therefore, was a less severe test of the trash rack than had been anticipated.

The head-discharge relations for the two prototype tests are plotted in figure 12. For comparison, the clear water test data are also plotted in figure 12. It is evident that during the first test the weir-flow heads were increased considerably by the trash which accumulated on the rack. Weir-flow coefficients as low as 1.35 were obtained in this test (fig. 13). These values are

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FIGURE 10.—Trash accumulation on the trash rack of the four-way drop inlet prototype after the first test.

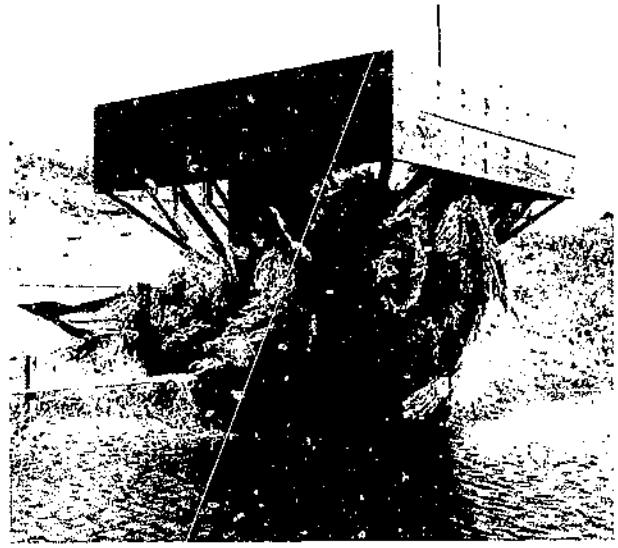

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FIGURE 11.—Trash accumulation on the trash rack of the four-way drop inlet prototype after the second test.

compared in table 2 with the clear water weir coefficient values for the largest weir-flow head before pipe flow started. At this head the trash-covered rack had a weir coefficient of 1.70 as compared with 3.53 for the clean rack. The test 1 reduction of the weir coefficient to 48 percent of its clear water value represents a reduction of 52 percent in discharge capacity, a sizable reduction to be caused by only 47 pounds of hay. For the second test, with 15 pounds of hay on the rack, the weir coefficient value was 2.50. This represents a reduction of 29 percent in the discharge capacity of the clean rack.

The crest-loss coefficients, K_c, are also listed in table 2. For both tests the coefficient increased from 0.49 for the clean rack to 1.17 for the trash-covered rack. This increase is not readily translated into discharge capacity reduction because K_c represents only a part of the head loss under pipe-flow conditions.

The model tests

In the model tests with flexible trash, various types and amounts of trash and several feeding rates were tried (table 3) to develop model trash flows similar to those of the prototype. For tests 53 and 54 the flexible trash was simulated with hemp fibers, obtained by cutting an old 3/8-inch-diameter hemp rope into 1-3/4-inch-long pieces with a bandsaw. The short pieces were hand-

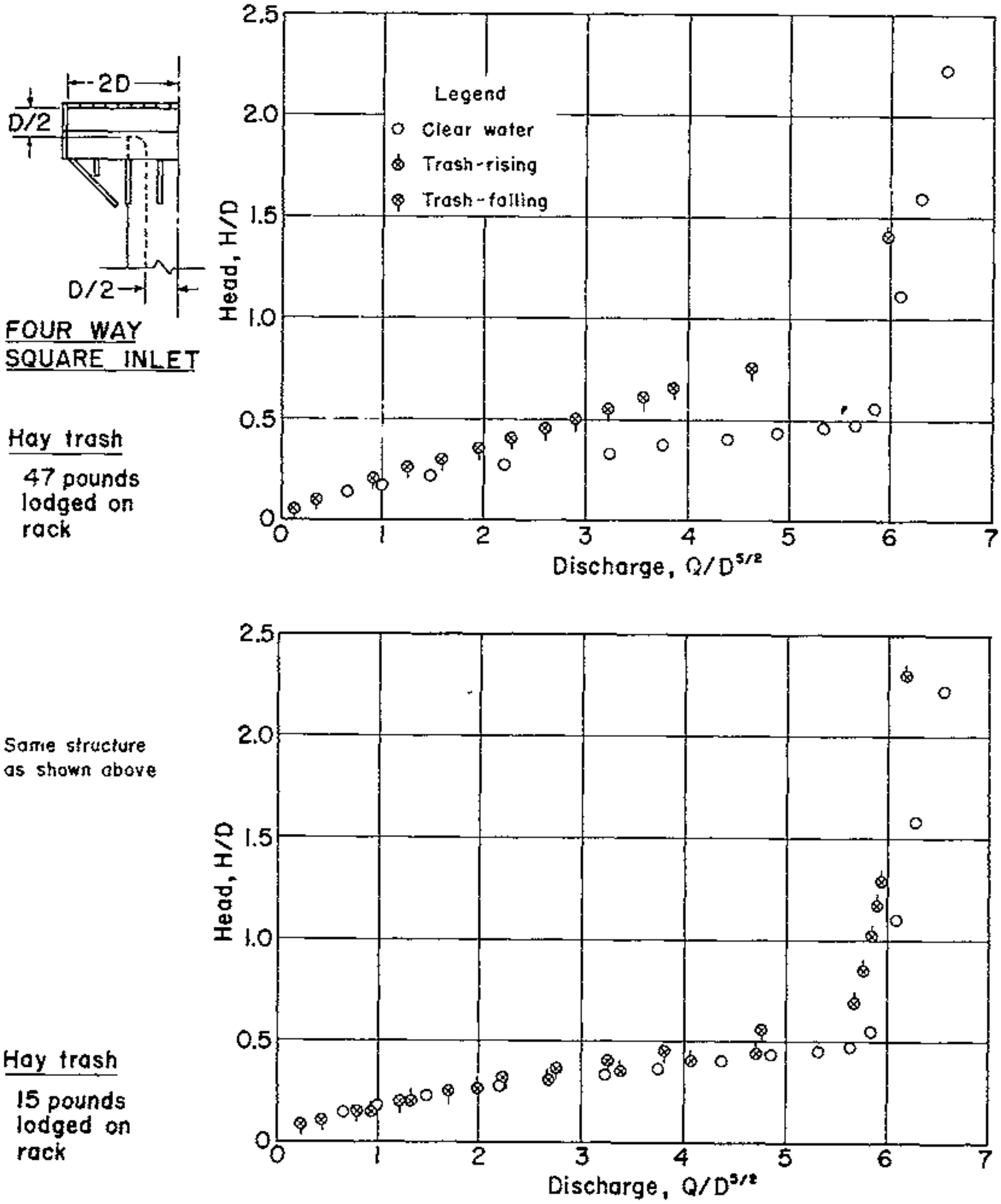


FIGURE 12.—Head-discharge relations for the four-way square drop inlet prototype.

separated into the individual strands—approximately 480 per piece. When straightened, the strands averaged 2-1/8 inches long. During test 53 approximately 250 grams of the hemp fibers were fed into the flow over a 4-hour period. This trash load contained an estimated 115,000 individual strands of hemp fiber. The fibers floated and moved toward the drop inlet with the flow. After the test was over the trash was found on top of the rack deck and on the basin floor. However, the load looked light compared with the hay load used in the tests on the full-size structure, so to 500 grams was used for test 54. After this test the trash pattern still did not look comparable with the full-scale pattern, so grass clippings obtained from mowing a lawn were tried for test 55. The clippings would not sink and move toward the rack, so this material was discarded as unsatisfactory for flexible-trash simulation.

The hemp fibers simulated hay better than the grass clippings, but they would not readily sink in the flow, and they were a little stiff and springy. After the oily coating was removed from the fibers with a dilute acid solution, their tendency to sink was sufficiently enhanced to make

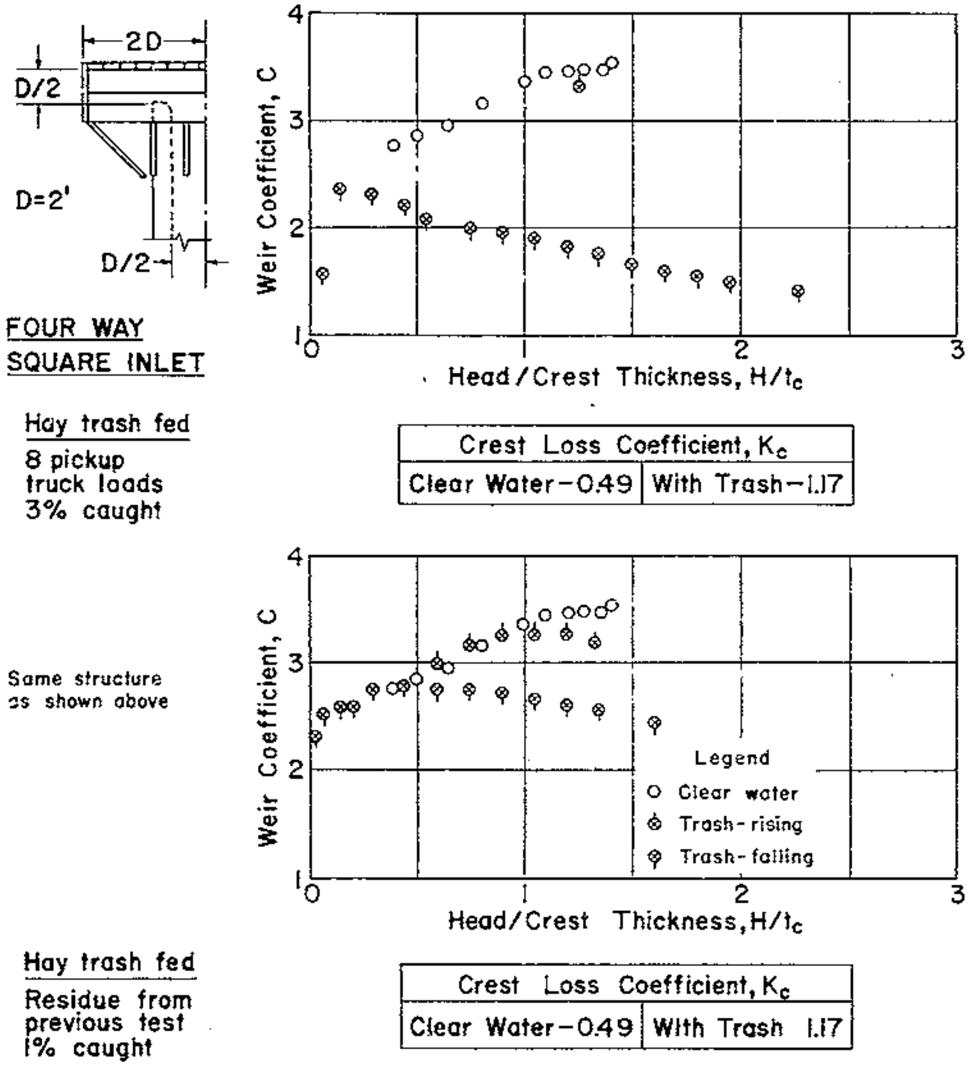


FIGURE 13.—Results of the flexible-trash test on the four-way square drop inlet prototype.

TABLE 2.—*Test results for four-way square drop inlet prototype*

Test No.	Trash load	Weir coefficient, C		Crest-loss coefficient, K_c		Trash caught (percent)
		Clear water	With trash	Clear water	With trash	
1	Hay (8 pickup loads)	3.53	1.70	0.49	1.17	3
2	Hay (residue from 1st test)	3.53	2.50	.49	1.17	1

TABLE 3.—*Flexible-trash model tests on four-way square drop inlet*

Test No.	Trash		Feeding time (minutes)	Remarks	Coefficients with trash[1]		Trash caught (percent)
	Type used	Amount fed (grams)			C	K_c	
53	Untreated hemp	250	240	Trash fed upstream of structure.	3.40	0.45	47
54	do.	500	255	do.	3.27	.60	38
[2]55	Grass clippings	...	...				
56	Treated hemp	420	180	Trash fed around structure.	3.20	.82	...
57	do.	995	330	do.	3.30	1.04	...
58	do.	930	195	do.	3.20	.50	...
[3]59	do.	840	185	do.	1.35	2.45	.
60	do.	1,020	170	do.	3.20	.47	. .
61	do.	1,000	170	Duplication of test 60	3.25	.46	. .
62	do.	1,030	180	do.	3.25	.46	...

[1] For clear water, weir coefficient $C=3.51$ and crest-loss coefficient $K_c=0.38$.
[2] No data were taken because the grass clippings would not sink.
[3] High sediment load in water.

them a suitable "model hay." This material is referred to in the text as treated hemp to distinguish it from the untreated hemp.

Tests 56 through 62 were run to develop a technique for the use of treated hemp fibers in the tests. The load and the feeding time used in test 58 produced a realistic trash accumulation on and around the rack and looked promising as a standard. Test 59 was intended to be a duplication of test 58 to check reproducibility of results. However, the water supply was a little muddy on the day of the test and sediment was filtered out by the mat of fibers around the rack. The accumulated sediment greatly increased the head loss through the mat of flexible trash on the rack, so test 59 was discarded as nonstandard. This test is still of considerable interest because it may represent an extreme, so the results are considered in the discussion.

Tests 60, 61, and 62 were alike in trash load and feeding time, with approximately 1,000 grams of trash fed at the rate of 30 grams every 5 minutes. Duplicate tests were run to check the reproducibility of results.

The trash load and feeding rate for the last three tests produced trash movement and accumulation patterns similar to those in the prototype tests, and are suitable for realistic model tests. In subsequent model tests the amount of trash was the same. The feed rate was increased to 40 grams every 5 minutes to reduce test time. Figures 14 and 15 show the model after tests 58 and 59.

The results of the flexible-trash tests on the model are given as weir coefficients in figures 16, 17, and 18 and are listed in table 3.

Figure 16 compares weir coefficients for three of the trash tests with weir coefficients for clear

PN—3613
FIGURE 14.—Model of trash rack on four-way drop inlet after flexible-trash test 58. Note the trash has dropped off bars.

PN—3614

FIGURE 15.—Sediment on trash after test 59 on the four-way drop inlet.

water tests. A 250-gram load of untreated hemp trash reduced the weir coefficient slightly, and doubling the trash load reduced it further. Table 3 shows reductions of 3 percent and 7 percent for tests 53 and 54, respectively. Approximately similar loads of untreated and treated hemp trash caused weir-coefficient reductions of 7 percent and 9 percent for tests 54 and 56, respectively.

The effect of trash feed rate on the weir coefficient can be evaluated by comparing the results for tests 57 and 58 (fig. 17 and table 3). The lower feed rate in test 57 caused a 6-percent reduction and the higher feed rate, a 9-percent reduction in weir coefficient. Figure 17 also shows the 62-percent reduction in the weir coefficient caused by sediment in the flow in test 59 with a trash load comparable to test 58 (9-percent reduction).

Figure 18 provides a ready comparison of the weir coefficients for the three tests having similar trash loads and feeding times, and shows that the test technique yields consistent and reproducible results.

The weir capacity of this structure was not materially reduced during trash-laden flows except for test 59, during which the water contained a high suspended-sediment load. The weir capacity for the other trash tests was at least 90 percent of the clear water capacity.

Table 3 shows that flexible trash caused no substantial increase in K_e in tests 53, 58, 60, 61, and 62. In these tests the head-pool surface was well above the top of the slotted deck, and flow entered the inlet through the slotted deck as well as through the rack bars. But during test 56 and most of tests 54 and 57, the head-pool level was near or below the top of the deck, and since all water had to flow through the trash in the rack, the K_e values increased substantially over the values for the clean water tests. For test 59 the head-pool level was above the deck, yet there was a large increase in K_e due to sediment accumulation in the trash.

The Hillside Inlet

The hillside inlet was used on many of the principal spillways in older upstream floodwater-retarding structures. Typical of these inlets is the one on the principal spillway at site 16 in the Sandstone Creek watershed of the Washita River Valley of Oklahoma. A sketch of the inlet is shown in figure 19. U.S. Geological Survey data on the outflow from the principal spillway and the corresponding pool elevations, made to determine the head-discharge relation for the spillway, were made available to the authors for use in this study. Measurements of two trash-laden flows as well as clear water flows were included so that performance of the trash rack in trash flow could be determined. The data also provided an opportunity to check the findings of model tests, by evaluating laboratory techniques against field experience. Accordingly, model tests of the site 16 structure were made in the laboratory, using an existing model which was similar to the field structure.

The ratio of the conduit diameter of this model to the prototype conduit diameter was 1 to 11.3. The proportions of the available model were not exactly like the prototype; thus, the scale ratios for the various components were different. A significant difference was that the prototype had a flat crest with the outside and inside edges beveled, whereas the model crest was flat for the outside half and rounded to a radius of one-half crest thickness for the inside half. To compare model and prototype performance, model weir

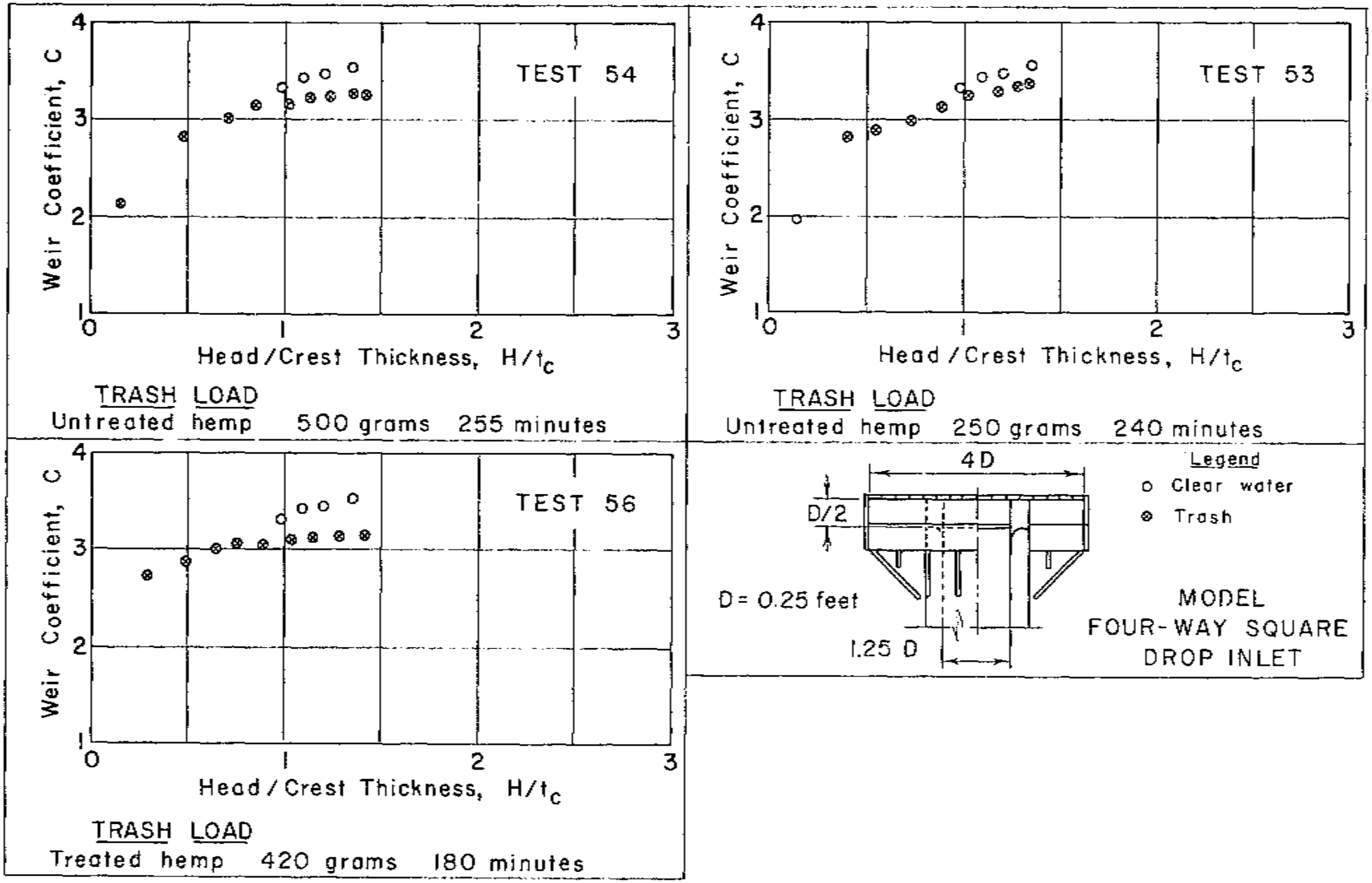


FIGURE 16.—Weir coefficients for four-way square drop inlet model: Comparisons between clear water and flexible-trash-laden flows for treated and untreated hemp and for different amounts and feeding rates of trash.

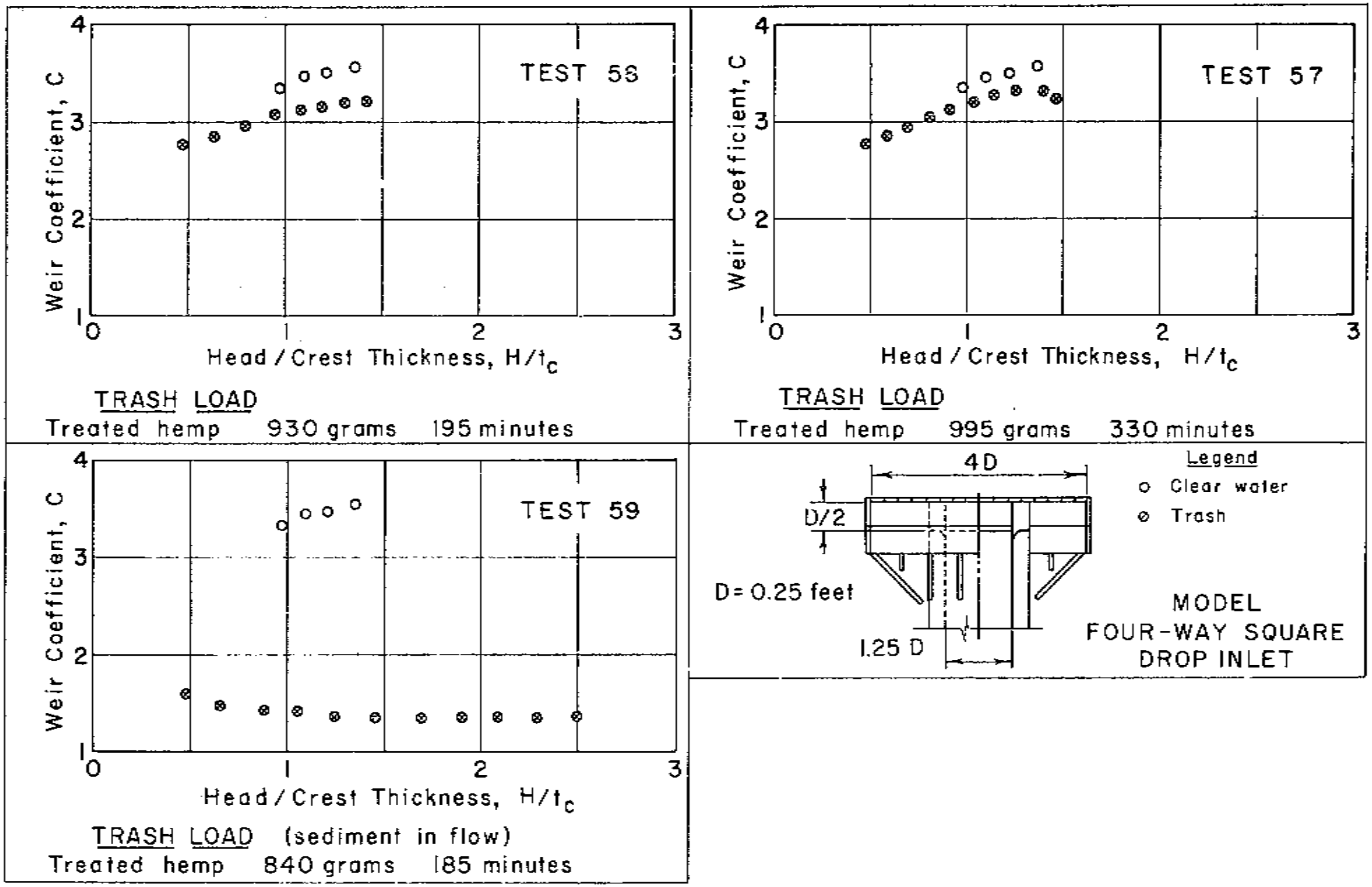


FIGURE 17.—Weir coefficients for four-way square drop inlet model: Comparisons between clear water and trash-laden flows for different feeding rates of treated hemp flexible trash.

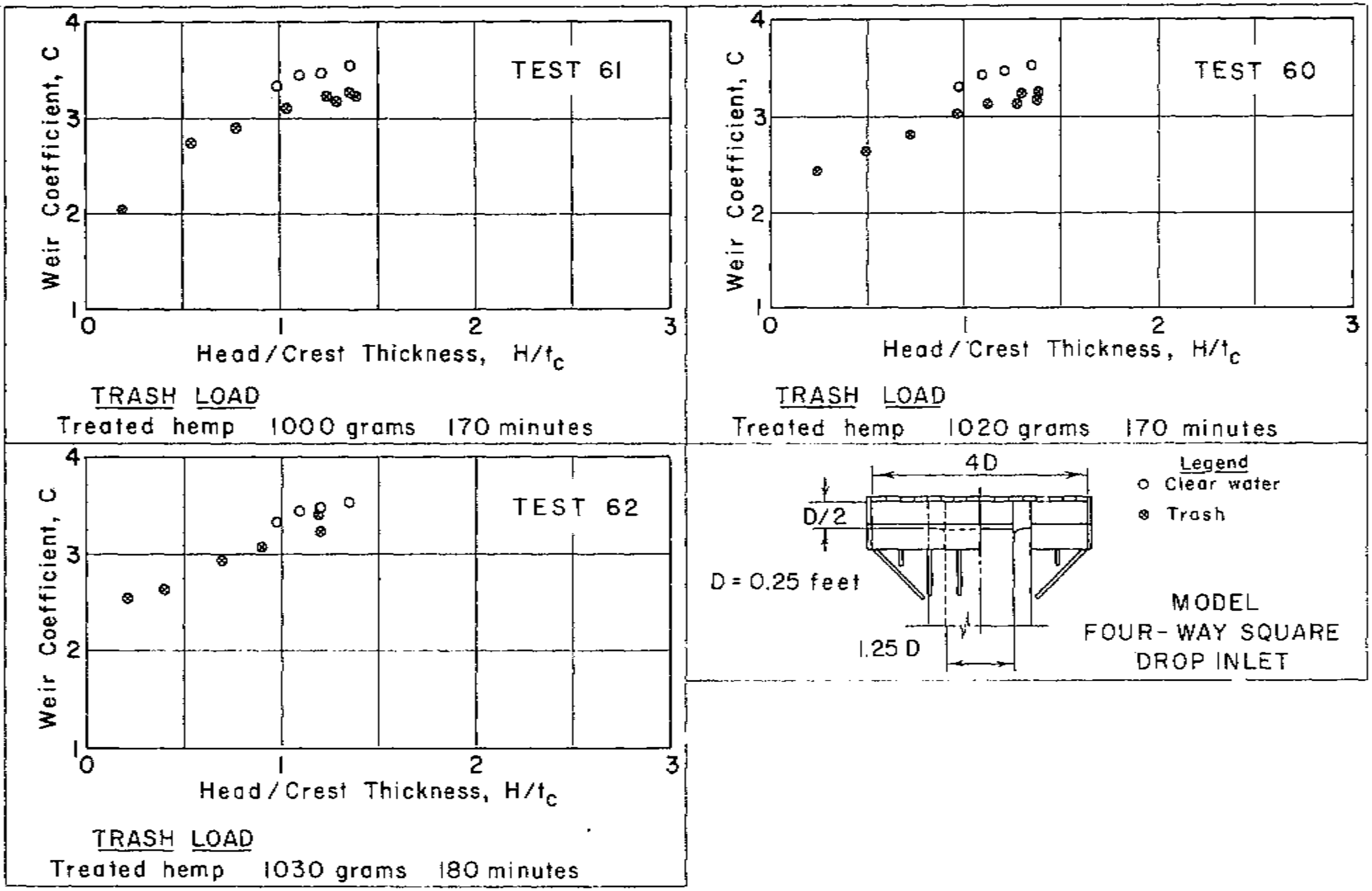


FIGURE 18.—Weir coefficients for four-way square drop inlet model: Three repetitions of a standard flexible-trash load to test consistency of results.

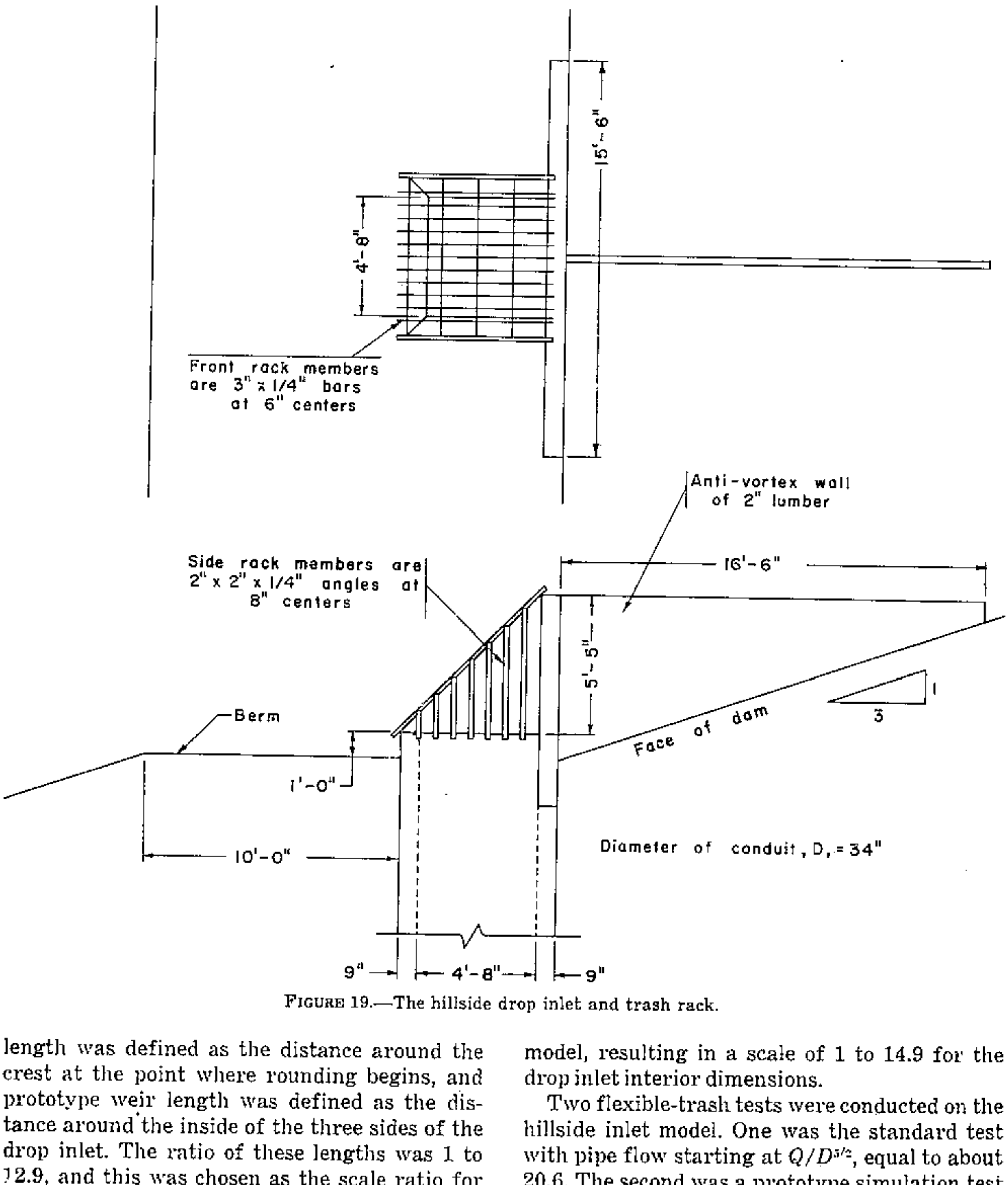


FIGURE 19.—The hillside drop inlet and trash rack.

length was defined as the distance around the crest at the point where rounding begins, and prototype weir length was defined as the distance around the inside of the three sides of the drop inlet. The ratio of these lengths was 1 to 12.9, and this was chosen as the scale ratio for the construction of the model rack and for the analysis and comparison of the weir-flow data.

Another difference between the model and prototype was the relatively thicker crest of the model, resulting in a scale of 1 to 14.9 for the drop inlet interior dimensions.

Two flexible-trash tests were conducted on the hillside inlet model. One was the standard test with pipe flow starting at $Q/D^{5/2}$, equal to about 20.6. The second was a prototype simulation test which required raising the outlet of the conduit discharge hose so that pipe flow would begin at $Q/D^{5/2}$=11.5. This criterion for simulation was developed from one field measurement with $Q=$

165 for H=8.09, and the scale ratio of 12.9. The significant difference between these two tests is the higher drop-inlet entrance velocity for the standard test than for the prototype simulation test at the start of pipe flow when trash feeding began. The standard trash load and feeding rate were applied in each test.

Figure 20 shows the trash on the model after the standard flexible-trash test. The head-discharge relationship and the weir coefficients for this test are plotted in figure 21. In calculating the dimensionless quantities for this plot, the actual diameter of the model conduit was used. Clear water test data are plotted on the same figure for comparison. It is evident that the trash accumulation on the rack greatly increased the head requirement for a given flow. Weir coefficients from the trash tests and the clear water

PN—3615

FIGURE 20.—Flexible trash collected on model of hillside inlet, site 16, Sandstone Creek watershed, Oklahoma, after standard flexible-trash test.

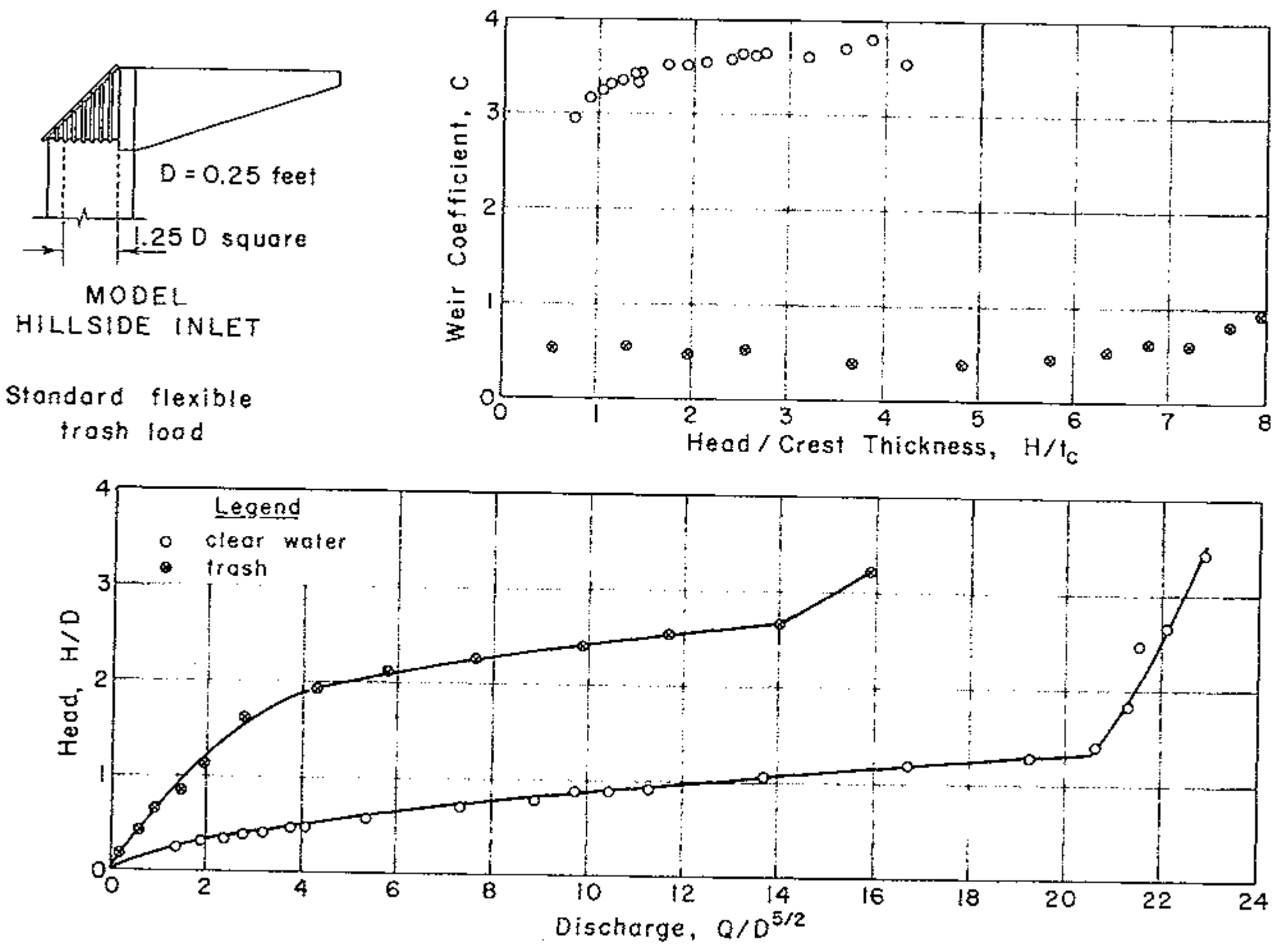


FIGURE 21.—Head-discharge relationships and weir coefficients for hillside inlet model.

tests all shown in figure 21. Crest-loss coefficients are given in table 4. For the standard test they were 0.23 for clear water and 4.49 for the trash flow. Flexible trash substantially reduced both the weir and the pipe-flow capacity of this structure.

Clear water and trash-laden flow head-discharge relationships for both the model and prototype for the prototype simulation tests are shown on figure 22. Prototype values for head and discharge are used in this figure. Model data were converted to prototype values by using the scale ratio of 1:12.9. The agreement between model and prototype rating data is good in the weir-flow range. Evidently, the choice of the weir lengths to establish the model-to-prototype scale ratio was the correct one. The success in getting the model to perform like the prototype in the pipe-flow range is evidenced by the good agreement between the model test and the two field observations. The scale ratio of the conduit diameter is not critical to pipe-flow simulation, because this simulation could have been handled by manipulations other than raising the elevation of the outlet. A constriction at the discharge end of the conduit would have served as well.

Weir coefficients for the prototype and the model are compared in figure 22. The difference in model and prototype values of C for clear water probably resulted from the difference in crest shapes. Crest-loss coefficients are given in table 4.

About 12 percent of the trash fed during the standard flexible-trash test caught on the rack and plugged the structure, enough to increase the crest-loss coefficient from 0.23 to 4.49. In the prototype simulation test, the lower velocities attracted less than 1 percent of the trash to the rack, but even this small amount increased the crest-loss coefficient from 0.21 to 2.32.

Two field measurements of discharge in the weir-flow range during trash flow also show the significant capacity reductions that trash can cause in this type of structure and trash rack. For one of these flows, the weir coefficient dropped to 0.07. See figure 22 for the plot of these two head-discharge measurements.

The Two-Way Drop Inlet

The two-way drop inlet, illustrated in figure 23, was designed by the Soil Conservation Service about 1957, soon after the trash-rack experiments were started at the laboratory. The inlet showed promise of being effective and practical so far as trash control was concerned, and its widespread use was anticipated. Therefore, it was subjected to intensive testing.

Two types were investigated, with solid and open-mesh side skirts. For each of these the effects of height and overhang of the plate and of the rack-bar spacing were determined. Figure 23 shows the variables investigated and gives their dimensions.

Two inlet lengths were tested, $2D$ and $3D$. Testing started with the $2D$-long inlet, and it therefore was subjected to some exploratory research and manipulations of variables which were not carried over to the testing of the $3D$-long inlet. For example, earlier tests had shown that rack-bar spacing was not important, so it was held constant at $D/3$ for the later tests.

Clear water and flexible-trash tests were performed on all racks, using the standard trash loads and feeding rates.

The clear water tests

The clear water tests were made as a basis for evaluation of rack performance under trash-

TABLE 4.—*Test results for four-way square drop inlet with hillside inlet*

Test scale	Trash load	Weir coefficient, C		Crest-loss coefficien, K_c		Trash caught (percent)
		Clear water	With trash	Clear water	With trash	
Model	Flexible, standard	3.7	0.5	0.23	4.49	12
Do.	Prototype simulation	3.7	.65	.21	2.32	1
Prototype	Actual field trash[1]	2.75	.07	...	...	..

[1] Field trash was probably a mixture of flexible and rigid.

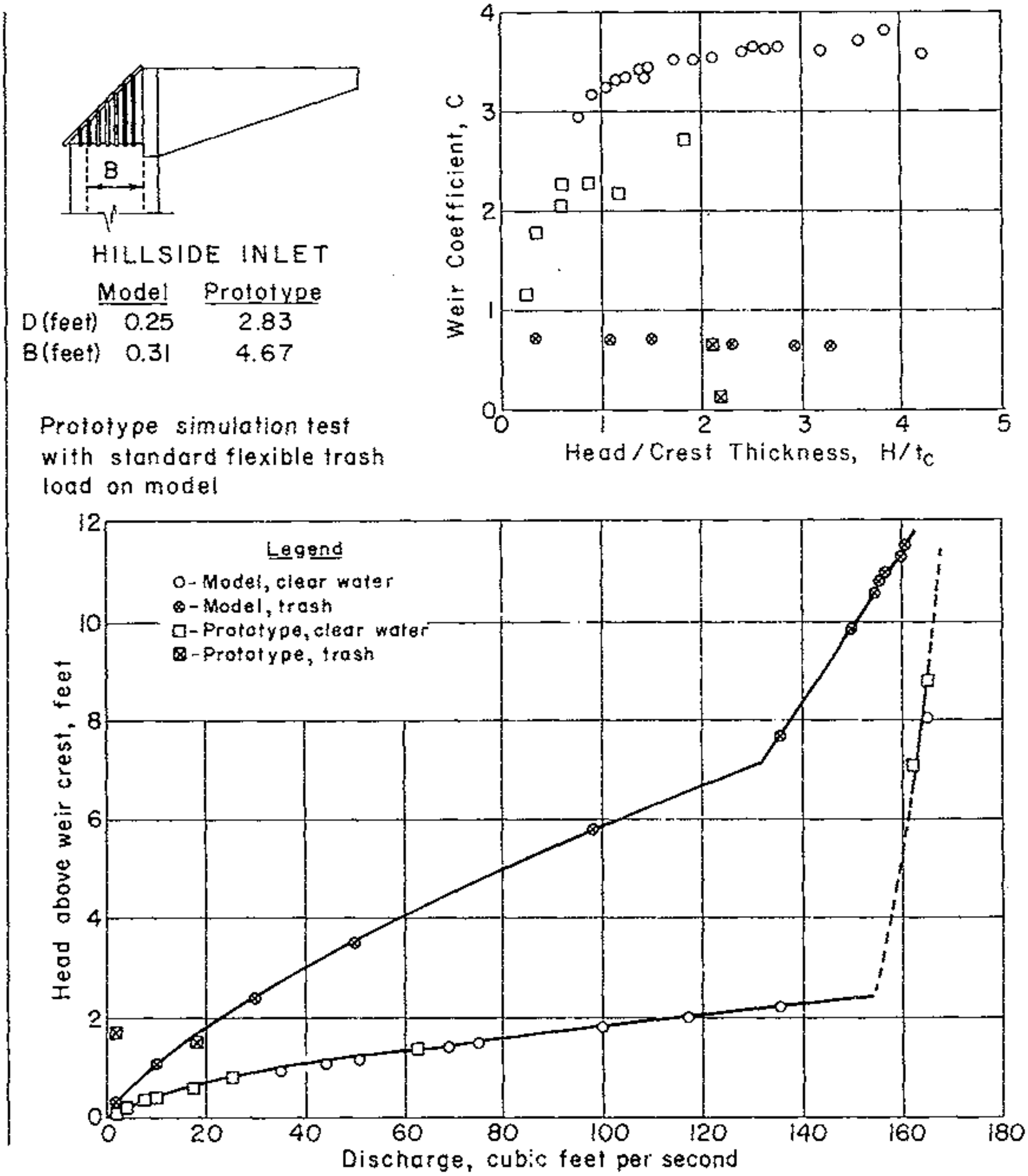
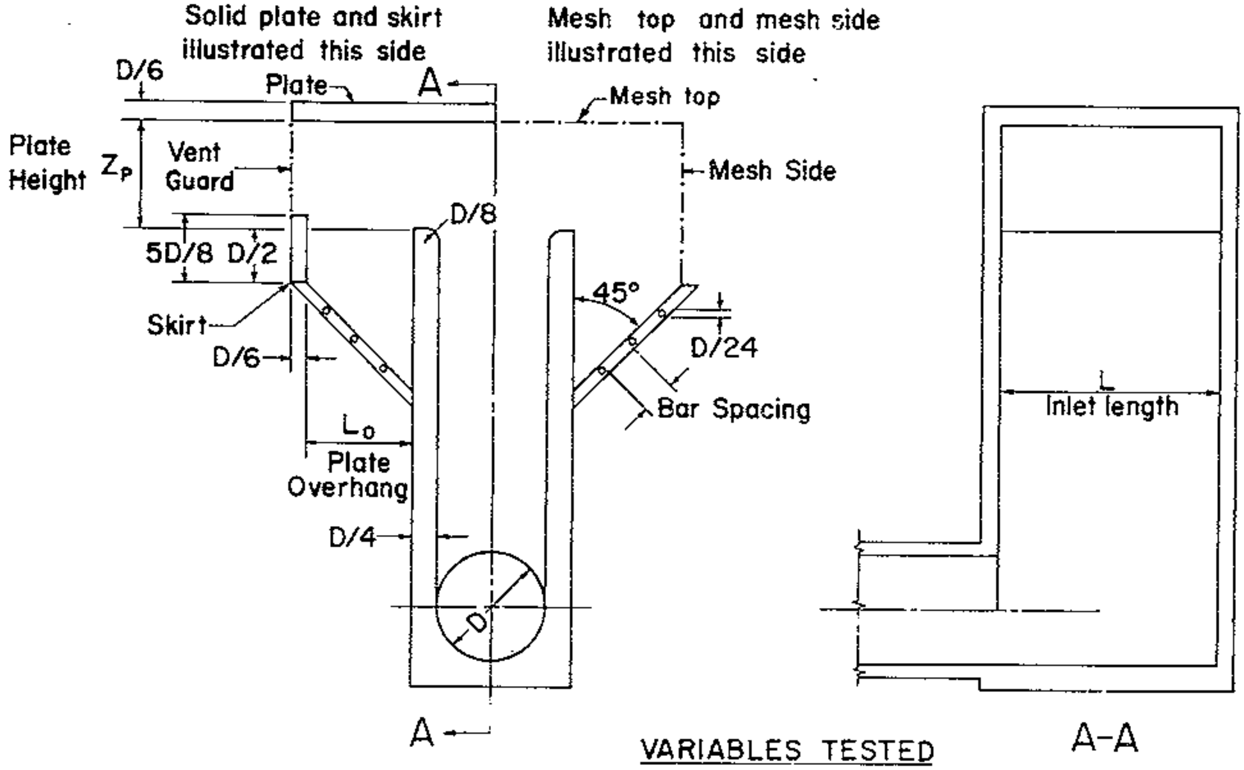


FIGURE 22.—Comparison of head-discharge relationships and weir coefficients for model and prototype of hillside inlet for clear water and trash-laden flows.

laden flows. The clear water tests also provide a measure of the effect of the rack alone on the performance of an inlet.

Head-discharge data are shown in figure 24 for clear water flow into a two-way drop inlet $2D$ long with a plate $D/2$ above the crest and having a D overhang. At a height of $D/2$ the plate level is below the intersection of a weir-flow curve and the pipe-flow curve for this inlet. Consequently, in the intermediate flow range, the head-discharge relation is controlled by the plate level.

The head-discharge relation for the plate-control region of this structure has been calculated



VARIABLES TESTED

L=2D (Inlet length)

Skirt type

Z_p = D, D/2

L_o = D, 3D/2

Vent Guard – 1 and 2 layers of hardware cloth

Bar Spacing = D/3, 4D/9

Plate – solid

Mesh Side type

Open area in mesh – 56%, 76%

Other variables same as for skirt type

L=3D

Skirt type

Same as for 2D long inlet except:

Bar Spacing = D/3 or no bars

Plate – solid or open mesh

Mesh Side type

Same as for skirt type

FIGURE 23.—The two-way drop inlet and variations tested.

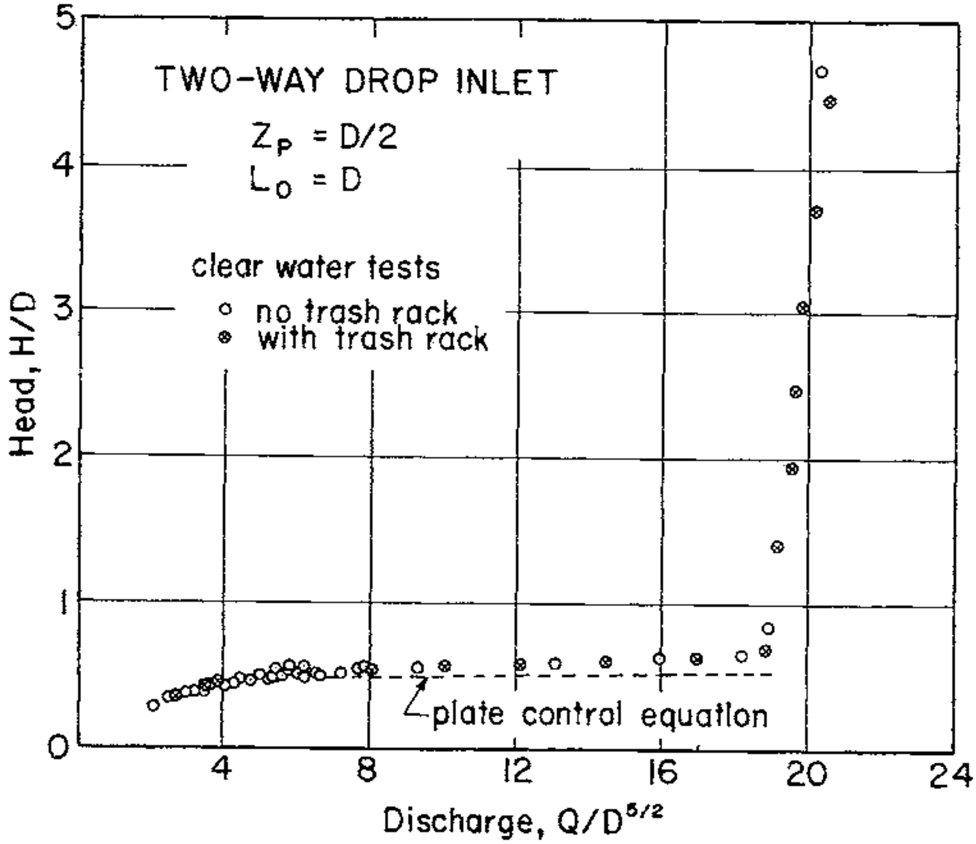


FIGURE 24.—Head-discharge relationships for two-way drop inlet comparing performance of drop inlet with and without rack bars.

from Donnelly, Hebaus, and Blaisdell's equation (equation 3) and plotted as a dash line on figure 24. The data points fall above this line indicating that, for a given discharge, a higher head occurred than was predicted by the equation. Rather than attempt to develop a new equation from less extensive data, to fit the observations better than Donnelly, Hebaus, and Blaisdell's equation, it was retained and coefficients applied to it. The validity of this approach was borne out by its use in defining the effect of trash on the head-discharge relation in the plate-control range.

Below the plate-control range the flow is controlled by the weir, and the head-discharge relation is $Q=C2LH^{3/2}$. Above the plate-control range the flow is controlled by the pipe system, and the head-discharge relation is

$$Q=A_p\sqrt{\frac{2g(H+Z)}{\Sigma K_s}} \qquad (5)$$

where A_p=barrel area,

g=acceleration of gravity,

Z=difference in elevation between weir crest and the centerline of the outlet of pipe,

ΣK_s=summation of loss coefficients including:

$K_r\left(\frac{A_p}{A_r}\right)^2$=crest-loss coefficient.

K_t=transition-loss coefficient.

$f\frac{l}{D}$=Friction-loss coefficient.

1=velocity-head coefficient.

C=a coefficient,

L=inlet length,

and Q and H=as previously defined.

Figure 24 also shows the head-discharge data for the same inlet after a trash rack was installed. This rack has solid skirts, three rack bars on each side, and two layers of hardware cloth for vent guards. The head-discharge data for the inlet with and without a trash rack show that the rack has little effect.

A more sensitive measure of the effect of a trash rack is the change in the discharge coefficient or head-loss coefficient caused by the installation of the rack. The weir-flow coefficients, C, are compared in figure 25 for plate heights $D/2$ and D. The C values are affected greatly by nappe clinging. During weir flow with clear water the nappes may cling to the sides of the drop inlet, or one nappe may cling to the side and the other spring free. The presence of a trash rack generally caused the nappes to spring free. Clinging obscures the comparison of C values for inlets with and without trash racks. Without a rack, and for the lower heads, the nappes cling and C values are high. For the higher heads the nappes spring free and the C values drop. With a rack in place the nappe springs free for all heads (within the testing range), and C values are lowered. Possibly turbulence in the flow induced by the trash-rack members inhibits nappe clinging.

The average values of plate-control coefficients, C_p, obtained from the tests on the drop inlet with plate height $D/2$ and plate overhang D were, without rack, 0.80 (range 0.78 to 0.82) and, with rack, 0.86 (range 0.80 to 0.92). The installation of the rack increased the discharge in the plate-control range by about 8 percent. No reason is known for this increase.

If the Donnelly, Hebaus, and Blaisdell formula had fit the data exactly, the value of C_p for the inlet without a rack would have been unity. Why it is less is not known. The models were calipered and the actual dimensions used in the solution of the equation. All observations, measurements, and calculations were routinely checked. Reconciling the difference would have required data, beyond that needed to meet the objectives of this experiment. The equation is, nevertheless, satisfactory as a base for comparison.

The effect of the trash rack on the head-discharge relation for this drop inlet in the pipe-control range was measured by the change in the crest-loss coefficient. Average values of K_c, the coefficient, obtained from the experiment are, without rack, 1.13, and with rack, 1.27. This small change in K_c (0.14) would have but little effect on discharge. For a typical closed-conduit spillway with loss coefficients totaling 3.5, this small change would reduce discharge by about 2 percent.

The effect of a trash rack on the head-discharge relation for a drop inlet has been examined and found to be relatively small. For drop inlets of other proportions and different trash-rack arrangements, effects of similar magnitude can be expected. Probably the greatest difference will be found in K_c, which varies considerably with plate height. The previous example was for a plate height of $D/2$. For a height of D the average K_c values were, without rack, 0.34, and with rack, 0.50.

The increase in K_c (0.16) is small and is of the same order of magnitude found for the inlet with plate height $D/2$.

TABLE 5.—*Approximate change in discharge capacity of a closed-conduit spillway following installation of a trash rack*

Flow range	Percentage change in discharge at—	
	Plate height D	Plate height $D/2$
Weir	−7	−7
Plate control	(1)	+8
Pipe control[2]	−3	−2

[1] Not applicable.

[2] For this estimate the sum of the loss coefficients exclusive of K_c was 2.37.

In table 5, the effects of a trash rack on the head-discharge relation for a drop inlet with the following characteristics are summarized: $2D$ long, with a solid plate extending a distance D beyond the outside face of the drop inlet wall; the trash rack has a solid skirt, a two-layer hardware cloth vent guard (56 percent net opening), and three rack bars.

The example chosen to illustrate the effect of a trash rack on the head-discharge relation for a drop inlet showed the crest-loss coefficient for plate height $D/2$ to be greater than for plate height D. This agrees with the findings of Hebaus[4] who has shown that crest losses should

[4] Hebaus, George G., 1969. Crest losses for two-way drop inlet. Proc. Am. Soc. Civ. Eng., J. Hydraul. Div. 95 (HY3): 919–940.

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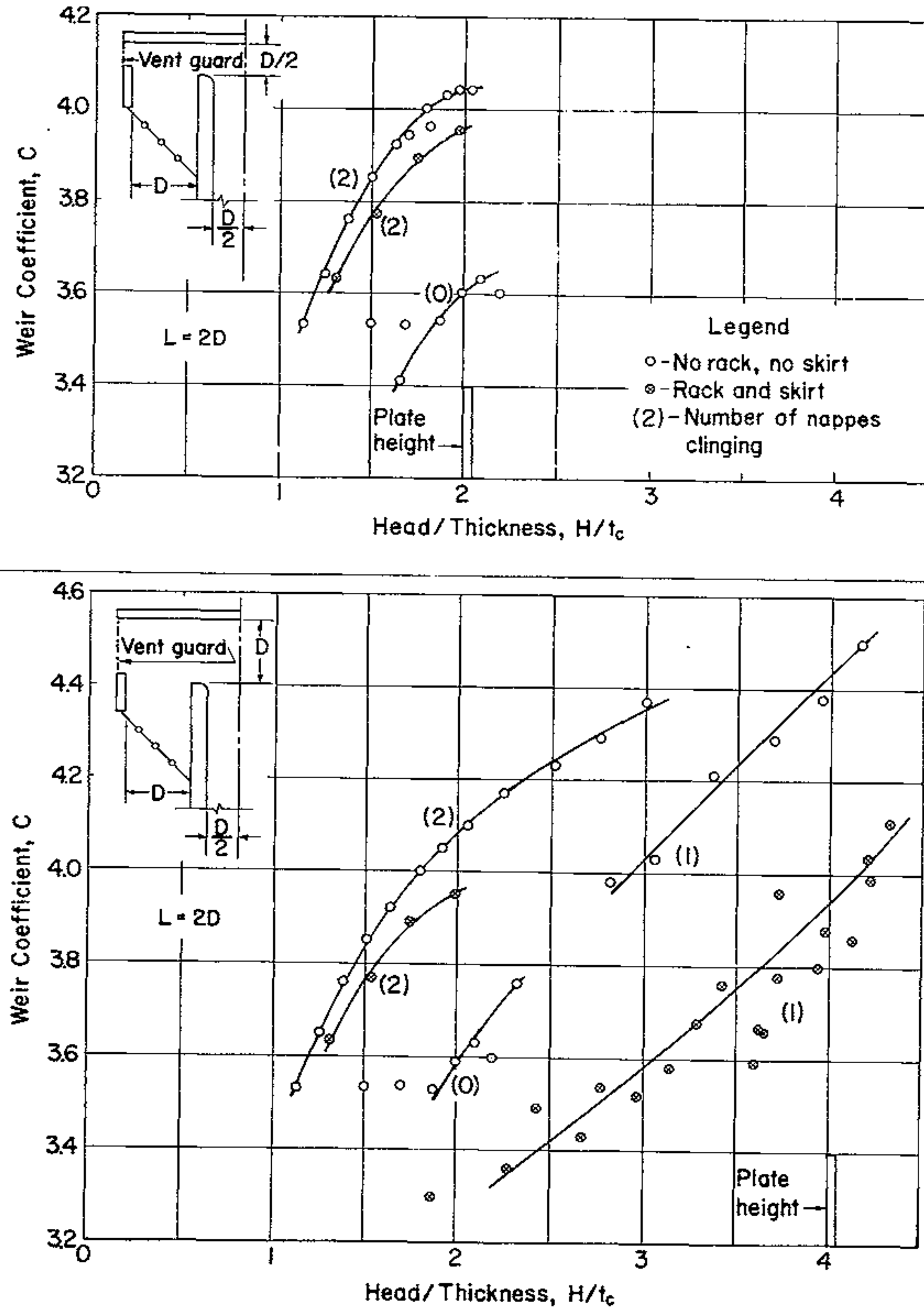


FIGURE 25.—Comparison of weir coefficients for drop inlets with and without trash racks for clear water flows.

theoretically increase as the antivortex plate is brought closer to the crest.

Crest-loss coefficients, K_c, were generally lower for trash racks with more open area. Therefore, an attempt was made to relate K_c to the net area of the trash rack. An early analysis seemed to indicate a systematic relationship, but although 32 combinations of variables were tested, no variable was tested over a wide enough range to reveal definite trends in the data. The use of net trash-rack area as a design parameter to predict K_c for trash-laden flows was, therefore, abandoned.

The trash tests

The performance data from the clear water and flexible trash tests on the trash racks for the 2*D*- and 3*D*-long two-way drop inlets are given graphically in figures 26 to 34 and listed in tables 6 and 7. These data include some measure-

TABLE 6.—*Test results for the 2D-long two-way model drop inlet*

Bar spacing, BS/D	Percentage open area above skirt or in mesh side	Weir coefficient, C		Plate-control coefficient, C_p		Crest-loss coefficient, K_c	
		Clear water[1]	With trash[2]	Clear water	With trash	Clear water	With trash
		Skirt, $Z_p/D=1/2$, $L_o/D=1$					
4/9	56	...	...	0.86	...	1.3	...
4/9	76	...	2.0	.84	0.40	1.2	4.6
1/3	76	...	1.5	...	.40	...	6.0
		Skirt, $Z_p/D=1/2$, $L_o/D=3/2$					
4/9	56	3.3	...	0.68	...	1.1	...
4/9	76	3.3	2.0	.62	0.42	1.1	3.6
1/3	76	...	1.7	...	.14	...	3.4
		Mesh side, $Z_p/D=1/2$, $L_o/D=1$					
4/9	76	...	1.4	...	0.27	...	5.3
1/3	76	...	1.4	...	.22	...	3.6
		Mesh side, $Z_p/D=1/2$, $L_o/D=3/2$					
4/9	76	3.6	0.8	0.79	0.10	1.1	5.1
1/3	76	...	1.2	...	.11	...	2.9
		Skirt, $Z_p/D=1$, $L_o/D=1$					
4/9	56	3.8	...	...	...	0.43	...
4/9	76	4.0	1.0	...	0.26	.43	3.5
1/3	76	4.6	1.0	...	.26	...	3.0
		Skirt, $Z_p/D=1$, $L_o/D=3/2$					
4/9	56	3.9	...	...	...	0.34	...
4/9	76	4.1	1.8	...	0.23	.33	2.4
1/3	76	...	1.4	...	1.6	.33	1.7
		Mesh side, $Z_p/D=1$, $L_o/D=1$					
4/9	56	4.0	...	...	...	0.39	...
4/9	76	3.9	1.0	...	0.27	.34	3.1
1/3	76	...	1.4	...	.37	.35	1.7
		Mesh side, $Z_p/D=1$, $L_o/D=3/2$					
4/9	76	4.2	1.3	...	0.16	0.29	2.2
1/3	76	...	1.4	...	.15	.28	1.3

[1] Clear water coefficient at same head at which lowest trash-flow coefficient observed.

[2] Lowest weir coefficient observed.

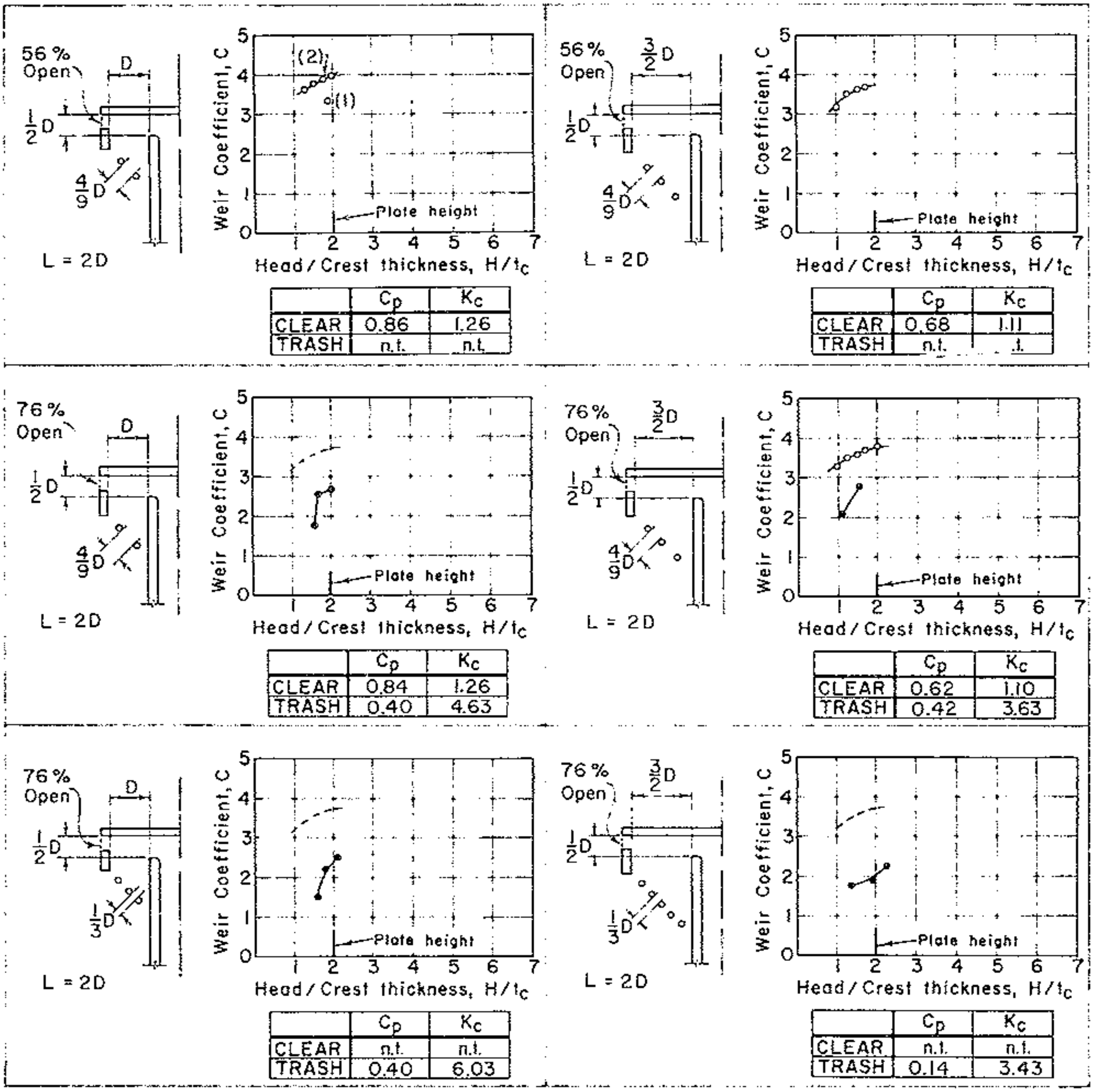
ments of trash passing the structure and of the various hydraulic coefficients. Plots are needed to show the weir coefficients because they vary with head and with the free or clinging state of the nappes. The plate-control coefficient, C_p, and the crest-loss coefficient, K_c, are reasonably constant for a particular structure and are satisfactorily characterized by a single value. A sketch of the rack and all performance data for clear and flexible trash-laden flow tests on an individual structure are given in one figure.

Weir-flow coefficients are plotted against the ratio of head-to-crest thickness in figures 26 to 34. The plots show a gradual increase in the weir coefficient with increasing head-to-crest thickness ratio, and then terminate at some upper

TABLE 7.—*Test result for the 3D-long two-way model drop inlet*

Plate	No. of bars[1]	Percentage open area above skirt or in mesh side	Weir coefficient, C		Plate-control coefficient, C_p		Crest-loss coefficient, K_c	
			Clear Water[2]	With trash[3]	Clear water	With trash	Clear water	With trash
			Skirt, $Z_p/D=1/2$, $L_o/D=1$					
Mesh	3	76	3.6	1.5	NA	NA	0.44	1.8
Solid	3	76	3.6	1.2	1.8	0.26	1.3	6.2
Do.	3	100	4.1	...	1.3	...	...	...
Do.	0	76	4.1	3.4	...	...	1.3	1.6
			Skirt, $Z_p/D=1/2$, $L_o/D=3/2$					
Mesh	5	76	3.7	1.8	NA	NA	0.42	1.4
Solid	5	76	3.7	1.2	1.2	0.09	1.2	4.7
Do.	5	100	3.7	...	1.4	...	...	...
			Skirt, $Z_p/D=1$, $L_o/D=1$					
Mesh	3	76	3.8	1.3	NA	NA	0.33	1.0
Solid	3	76	3.8	1.0	NA	0.30	.47	3.3
Do.	3	100	4.1	...	...	...	...	...
			Skirt, $Z_p/D=1$, $L_o/D=3/2$					
Mesh	5	76	...	1.5	NA	NA	0.42	0.53
Solid	5	76	4.1	1.1	NA	0.12	.47	2.6
Do.	5	100	4.1	...	...	...	...	...
			Mesh side, $Z_p/D=1/2$, $L_o/D=1$					
Mesh	3	76	...	1.6	...	...	0.38	1.7
Solid	3	76	...	1.3	...	0.20	1.3	5.7
			Mesh side, $Z_p/D=1/2$, $L_o/D=3/2$					
Mesh	5	76	3.9	1.9	...	...	0.43	1.3
Solid	5	76	...	1.6	...	0.10	1.2	3.2
			Mesh side, $Z_p/D=1$, $L_o/D=1$					
Mesh	3	76	...	1.4	NA	NA	0.29	0.80
Solid	3	76	4.0	1.3	NA	0.29	.48	3.0
			Mesh side, $Z_p/D=1$, $L_o/D=3/2$					
Mesh	5	76	...	1.5	NA	NA	0.32	0.62
Solid	5	76	4.1	1.3	NA	0.18	.37	1.6

NA Not applicable.
[1] All bars spaced $D/3$.
[2] Clear water coefficient at same head at which lowest trash-flow coefficient observed.
[3] Lowest weir coefficient observed.



56% open, overhang D, 4/9 D spacing:

	C_p	K_c
CLEAR	0.86	1.26
TRASH	n.t.	n.t.

56% open, overhang 3/2 D, 4/9 D spacing:

	C_p	K_c
CLEAR	0.68	1.11
TRASH	n.t.	n.t.

76% open, overhang D, 4/9 D spacing:

	C_p	K_c
CLEAR	0.84	1.26
TRASH	0.40	4.63

76% open, overhang 3/2 D, 4/9 D spacing:

	C_p	K_c
CLEAR	0.62	1.10
TRASH	0.42	3.63

76% open, overhang D, 1/3 D spacing:

	C_p	K_c
CLEAR	n.t.	n.t.
TRASH	0.40	6.03

76% open, overhang 3/2 D, 1/3 D spacing:

	C_p	K_c
CLEAR	n.t.	n.t.
TRASH	0.14	3.43

Legend: ○ Clear water tests
⊗ Trash laden water tests
( )-Numeral within indicates number of nappes clinging to crest
n.a-Not applicable
n.t.-No test

FIGURE 26.—Results of flexible-trash tests on two-way drop inlets 2*D* long, with skirt and with *D*/2 plate height for various bar spacings and vent guard areas and for plate overhangs of *D* and 3*D*/2.

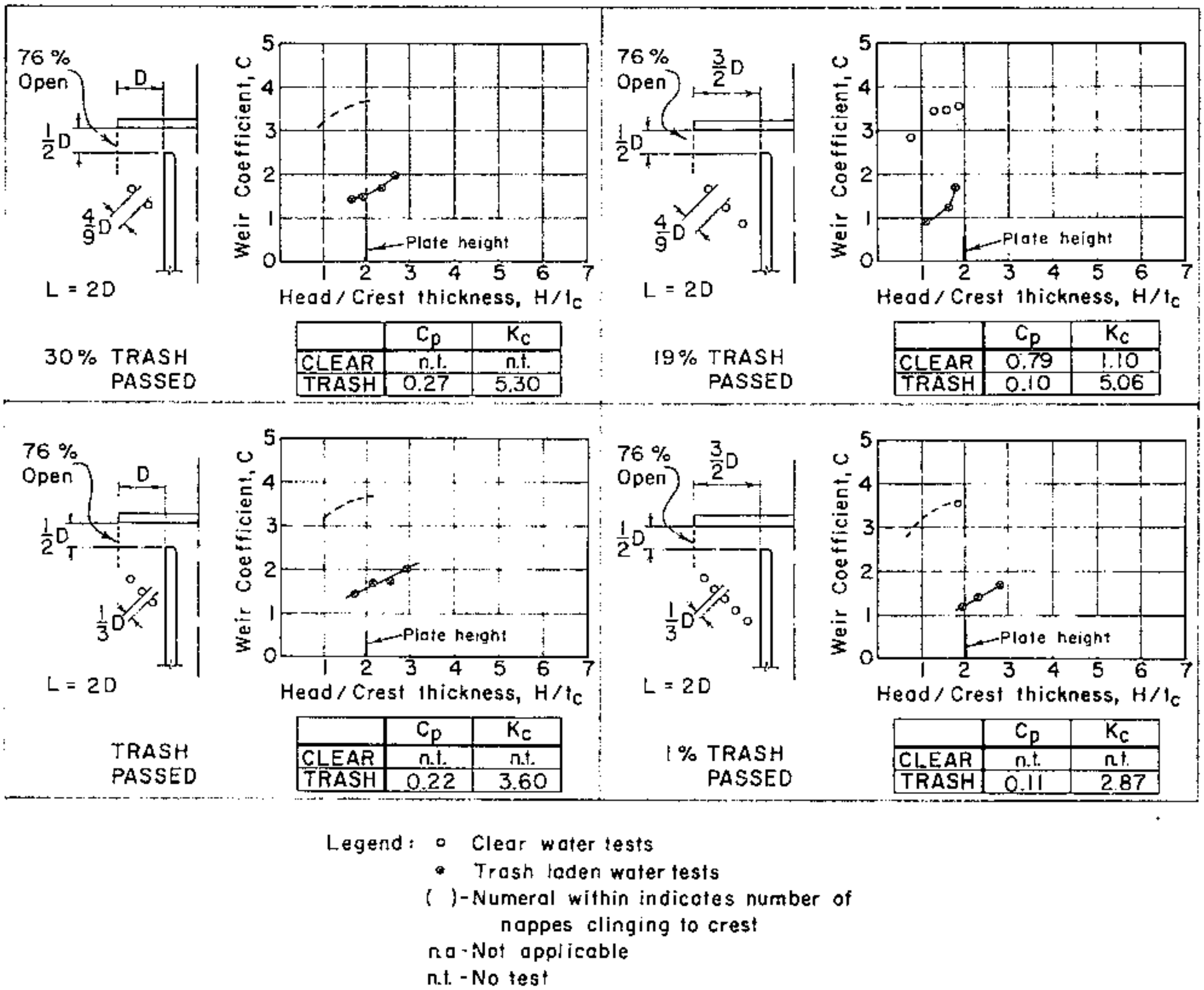
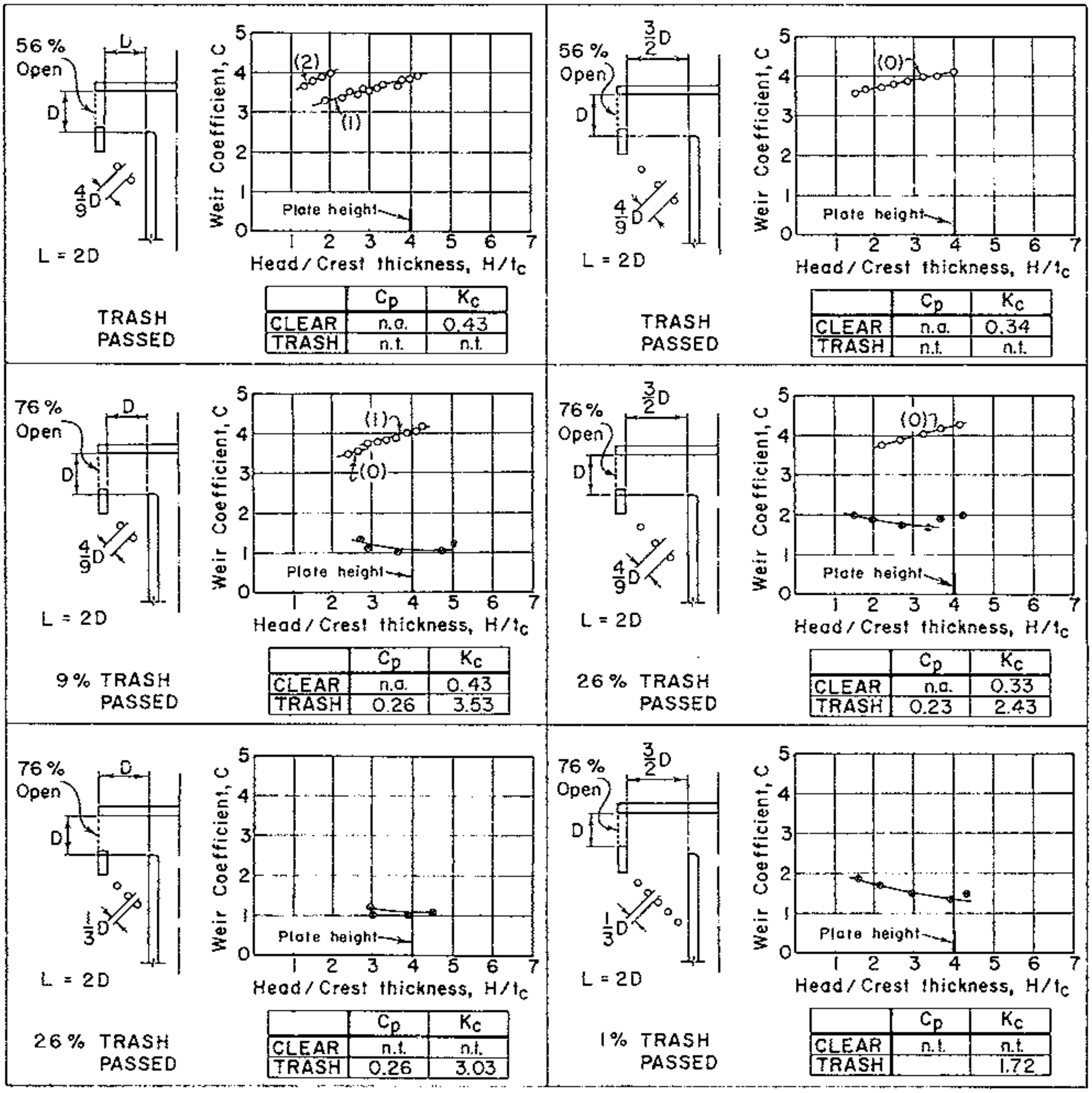


FIGURE 27.—Results of flexible-trash tests on two-way drop inlets $2D$ long, with mesh side and with $D/2$ plate height for various bar spacings and vent guard areas and for plate overhangs of D and $3D/2$.

value of the ratio, at which another flow mode (either plate control or pipe control) succeeds the weir-control mode. For racks with a plate height of $D/2$, weir control for clear water flow ends when the water level (head) is at or near the level of the underside of the deck. Weir coefficients calculated for flows above this level increase very rapidly. This sudden rise in coefficient is an indication that plate control has taken over. During trash-laden flow it is possible for the water level to rise above the plate and still have weir control. See figure 32 for examples. Head loss through the mat of accumulated trash will cause a drop in the water surface profile through the mat. Consequently, the water level in the reservoir may be above the plate height but below the plate height after the water has flowed through the mat.

Two bar spacings were tested on the $2D$-long drop inlet. Little difference was found in the coefficients for the two spacings. Table 8 lists the average values of the three coefficients for clear and for trashy flows.

(Continued on p. 33.)



	C_p	K_c
CLEAR	n.a.	0.43
TRASH	n.t.	n.t.

	C_p	K_c
CLEAR	n.a.	0.34
TRASH	n.t.	n.t.

	C_p	K_c
CLEAR	n.a.	0.43
TRASH	0.26	3.53

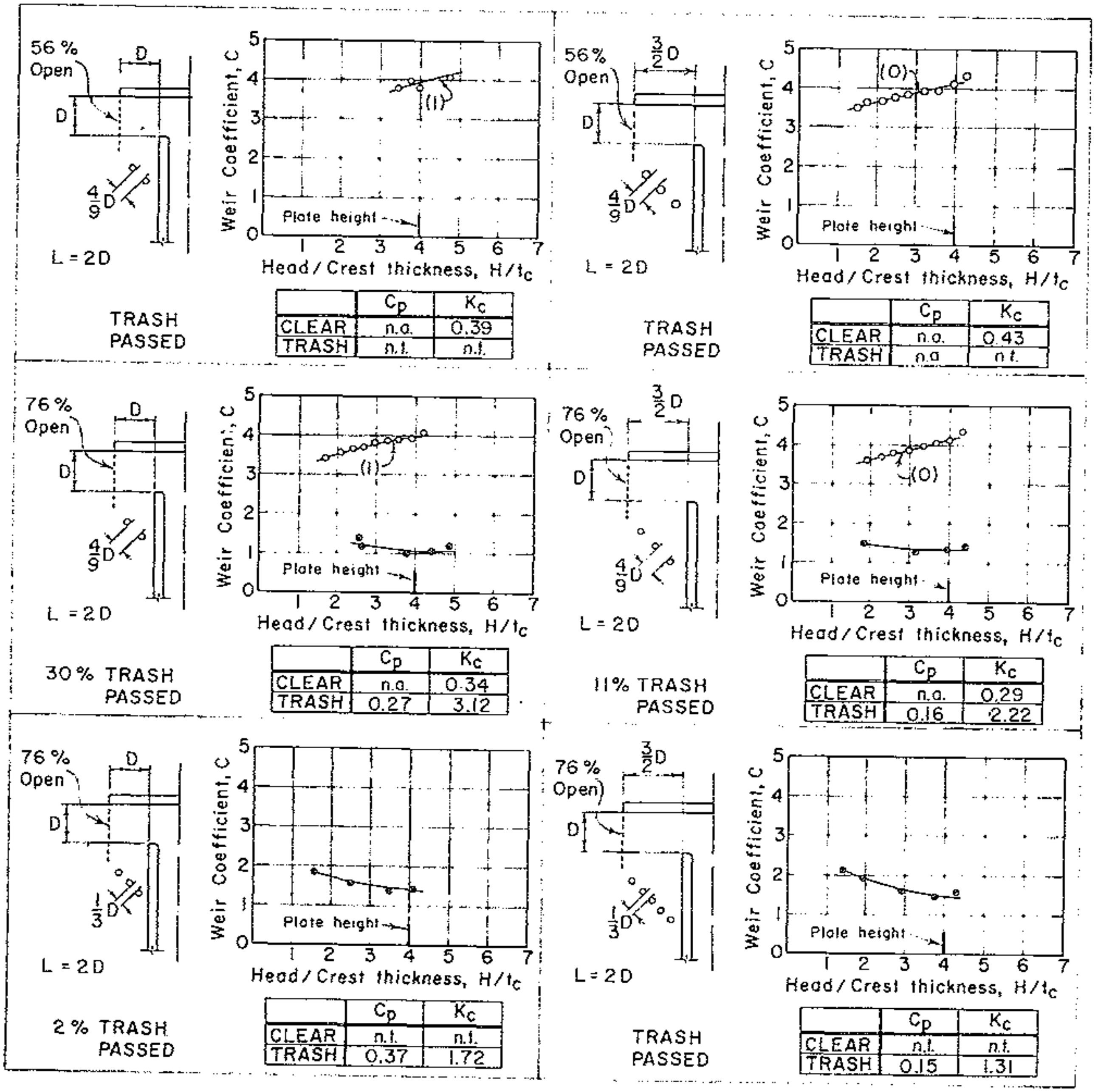
	C_p	K_c
CLEAR	n.a.	0.33
TRASH	0.23	2.43

	C_p	K_c
CLEAR	n.t.	n.t.
TRASH	0.26	3.03

	C_p	K_c
CLEAR	n.t.	n.t.
TRASH		1.72

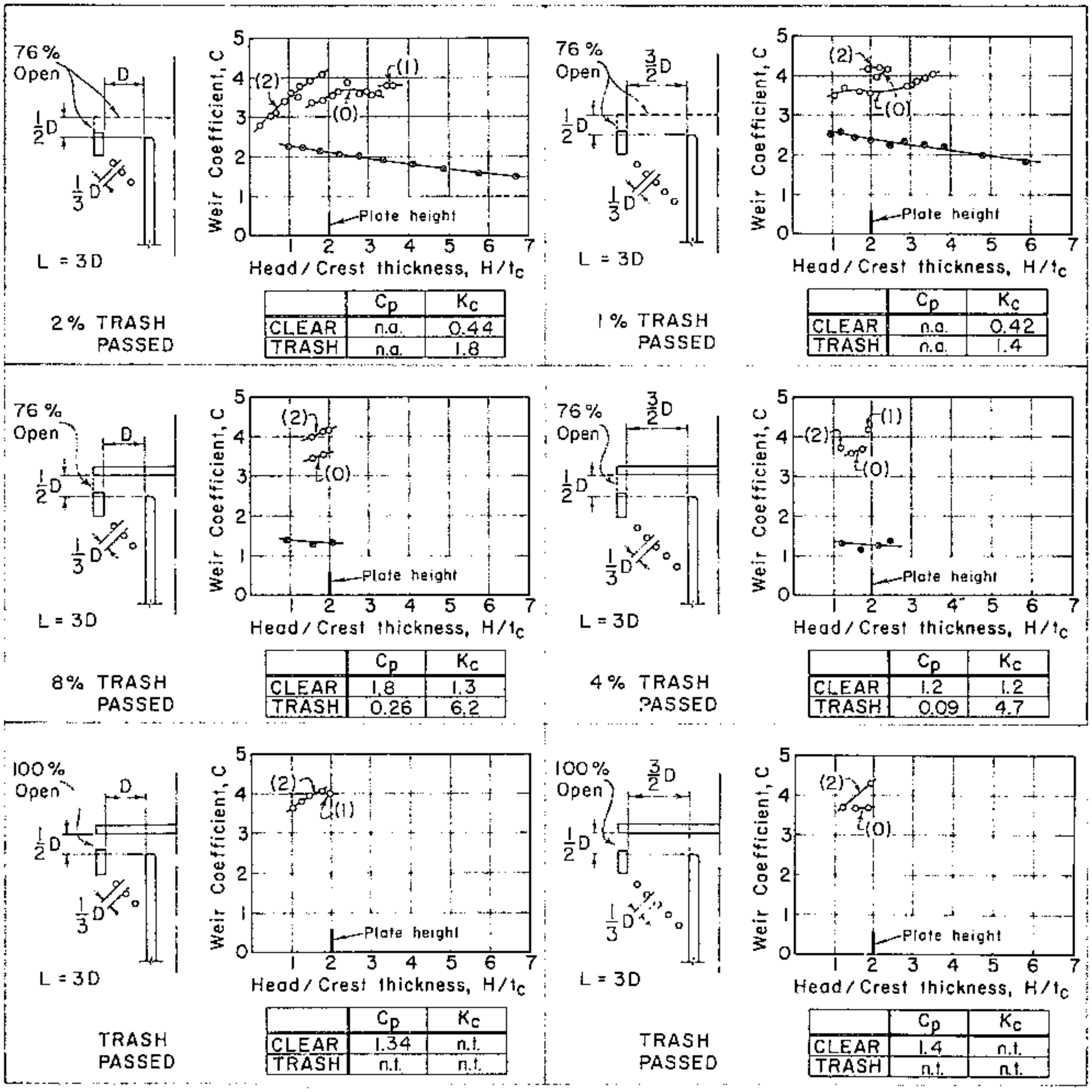
Legend: ∘ Clear water tests
• Trash laden water tests
( )-Numeral within indicates number of nappes clinging to crest
n.a - Not applicable
n.t. - No test

FIGURE 28.—Results of flexible-trash tests on two-way drop inlets 2*D* long, with skirt and with *D* plate height for various bar spacings and vent guard areas, and for plate overhangs of *D* and 3*D*/2.



Legend: ○ Clear water tests
● Trash laden water tests
( )-Numeral within indicates number of nappes clinging to crest
n.a - Not applicable
n.t. - No test

FIGURE 29.—Results of flexible-trash tests on two-way drop inlets 2*D* long, with mesh side and with *D* plate height for various bar spacings and vent guard areas and for plate overhangs of *D* and 3*D*/2.



2 % TRASH PASSED

	C_p	K_c
CLEAR	n.a.	0.44
TRASH	n.a.	1.8

1 % TRASH PASSED

	C_p	K_c
CLEAR	n.a.	0.42
TRASH	n.a.	1.4

8 % TRASH PASSED

	C_p	K_c
CLEAR	1.8	1.3
TRASH	0.26	6.2

4 % TRASH PASSED

	C_p	K_c
CLEAR	1.2	1.2
TRASH	0.09	4.7

TRASH PASSED

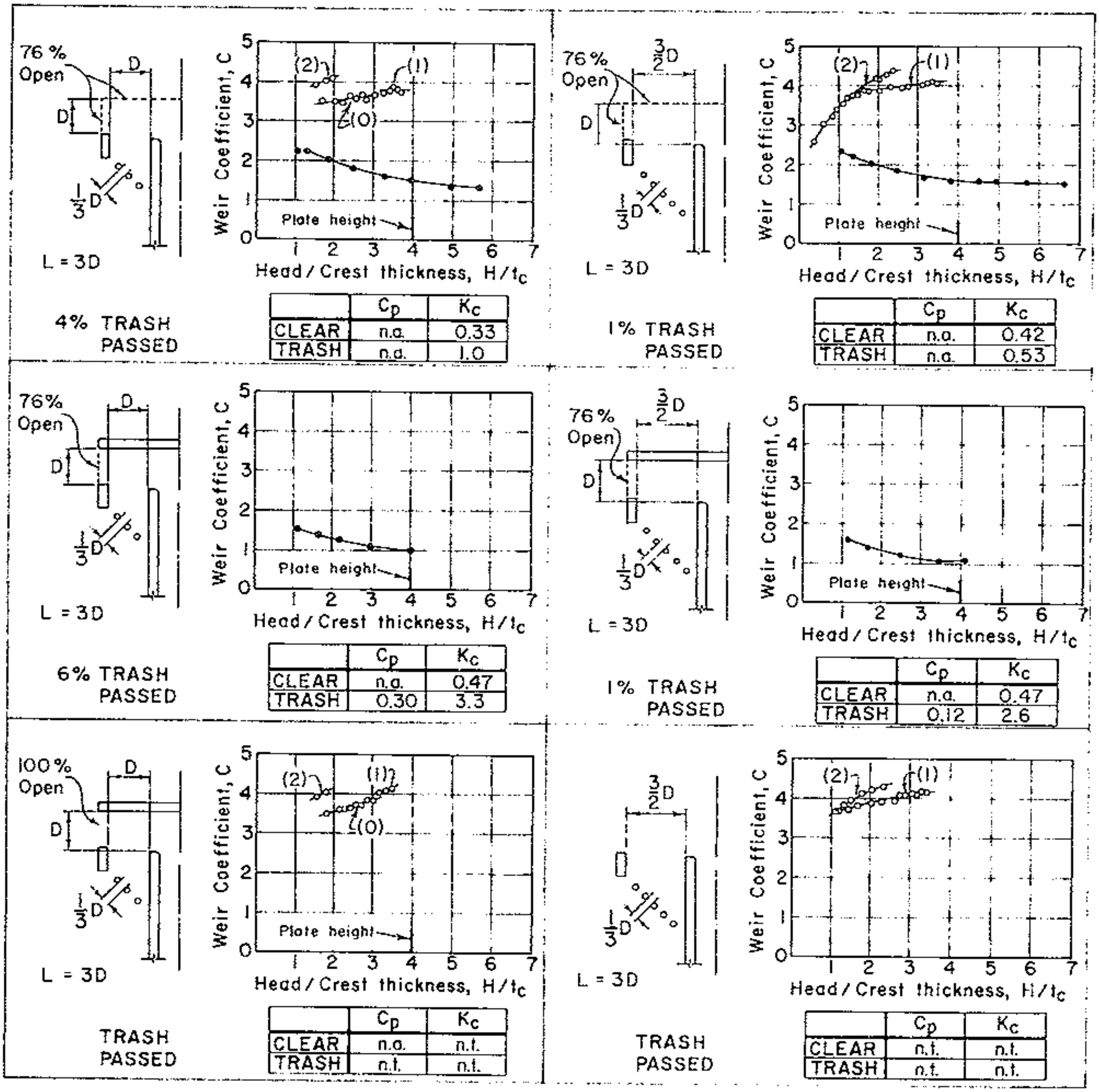
	C_p	K_c
CLEAR	1.34	n.t.
TRASH	n.t.	n.t.

TRASH PASSED

	C_p	K_c
CLEAR	1.4	n.t.
TRASH	n.t.	n.t.

Legend: ∘ Clear water tests
• Trash laden water tests
( )-Numeral within indicates number of nappes clinging to crest
n.a - Not applicable
n.t. - No test

FIGURE 30.—Results of flexible-trash tests on two-way drop inlets 3*D* long, with *D*/2 plate height and with skirt for solid and open mesh plates and for plate overhangs of *D* and 3*D*/2.



4% TRASH PASSED

	C_p	K_c
CLEAR	n.a.	0.33
TRASH	n.a.	1.0

1% TRASH PASSED

	C_p	K_c
CLEAR	n.a.	0.42
TRASH	n.a.	0.53

6% TRASH PASSED

	C_p	K_c
CLEAR	n.a.	0.47
TRASH	0.30	3.3

1% TRASH PASSED

	C_p	K_c
CLEAR	n.a.	0.47
TRASH	0.12	2.6

TRASH PASSED

	C_p	K_c
CLEAR	n.a.	n.t.
TRASH	n.t.	n.t.

TRASH PASSED

	C_p	K_c
CLEAR	n.t.	n.t.
TRASH	n.t.	n.t.

Legend: ∘ Clear water tests
• Trash laden water tests
( )-Numeral within indicates number of nappes clinging to crest
n.a.-Not applicable
n.t.-No test

FIGURE 31.—Results of flexible-trash tests on two-way drop inlets 3*D* long, with *D* plate height and with skirt for solid and open mesh plates and for plate overhangs of *D* and 3*D*/2.

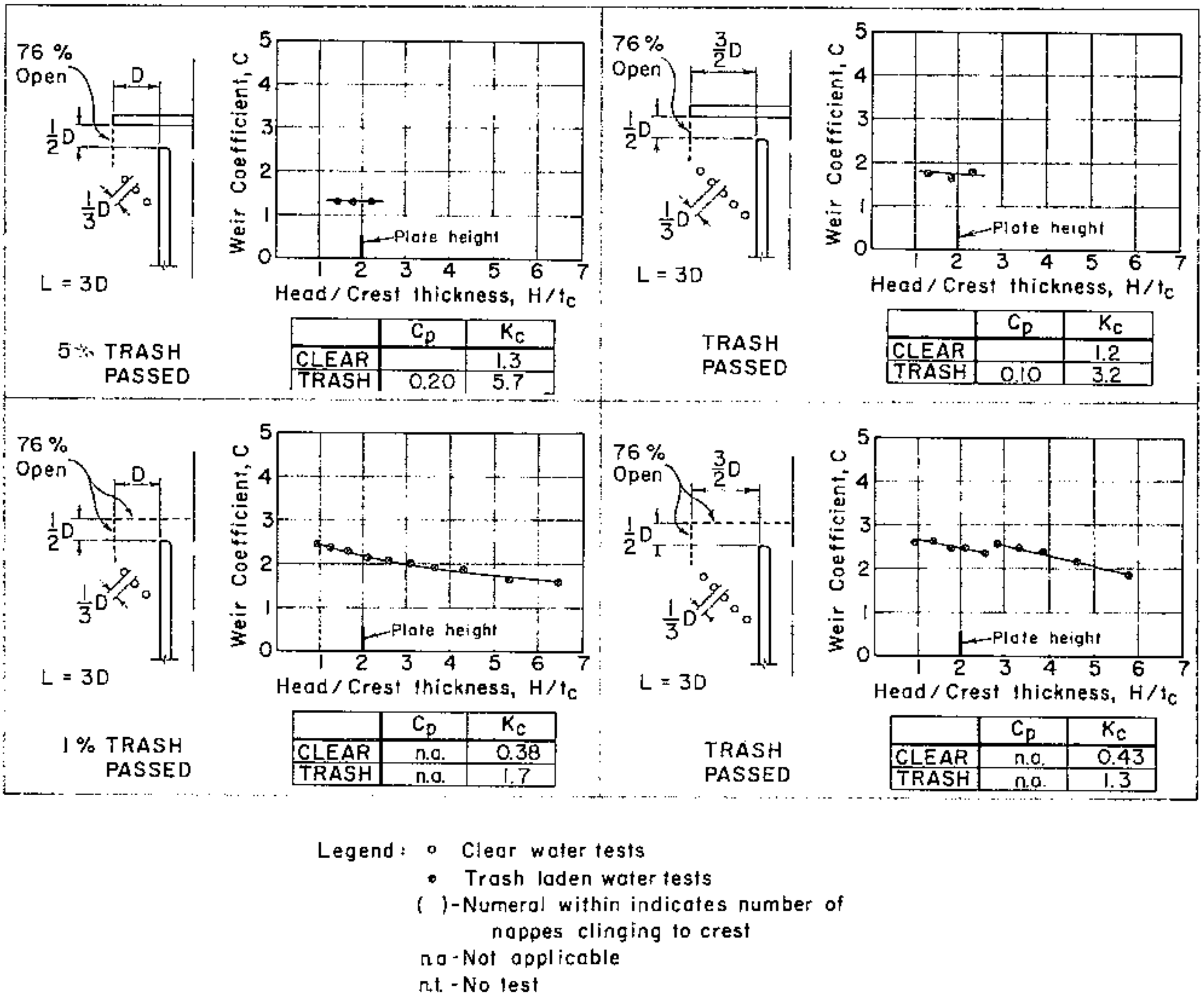


FIGURE 32.—Results of flexible-trash tests on two-way drop inlets 3D long, with D plate height and with mesh side for solid and open mesh plates and for plate overhangs of D and 3D/2.

TABLE 8.—*Average coefficient values in two-way drop inlets with trash racks, with different bar spacings*

Coefficient	Flow	Bar spacing 4D/9	Bar spacing D/3
Weir, C	Clear	4.0	4.0
Do.	Trash	1.38	1.42
Plate control, C_p	Clear	...	...
Do.	Trash	.23	.28
Crest loss, K_c	Clear	.50	.52
Do.	Trash	2.95	3.74

The difference in coefficients for the two spacings is small and probably not significant, especially for the trash-laden flows, for which the variability is high. Therefore, bar spacing was dropped as a variable in the subsequent experiments on the 3D-long drop inlet.

Two percentages of open area for the side vent above the skirt or for the mesh side were tested. Table 9 lists the average values of the three coefficients in clear water tests.

Because the differences in the coefficients for the two percentages of open area in the side vents are very small, percentage of open area was also dropped as a variable in the experiments on the 3D-long drop inlet.

The results of the tests on the 3D-long, two-

TABLE 9.—*Average clear-flow coefficients in 2D-long, two-way drop inlets with trash racks, with different percentages of side-vent open area*

Coefficient	Percentage of open area in side vent or mesh side	
	56	76
Weir, C	3.72	3.82
Plate control, C_p	.77	.73
Crest loss, K_c	.82	.80

way drop inlet trash racks are summarized in table 7. The data are grouped by height and overhang of the plate and by the type of side panel, skirt, or open mesh. Within each group, results are given for both a mesh and a solid plate. Also, for the racks with skirts, results are shown for tests made with no mesh covering the open space between the top of the skirt and the underside of the plate. Weir- and plate-control discharge coefficients and crest-loss coefficients are given for both clear and flexible trash-laden flows.

Plate control cannot occur for the mesh plate and did not occur in these experiments for any plate at height D with clear water flows.

The open mesh plate was new to the $3D$-long drop inlet tests and reflected new developments

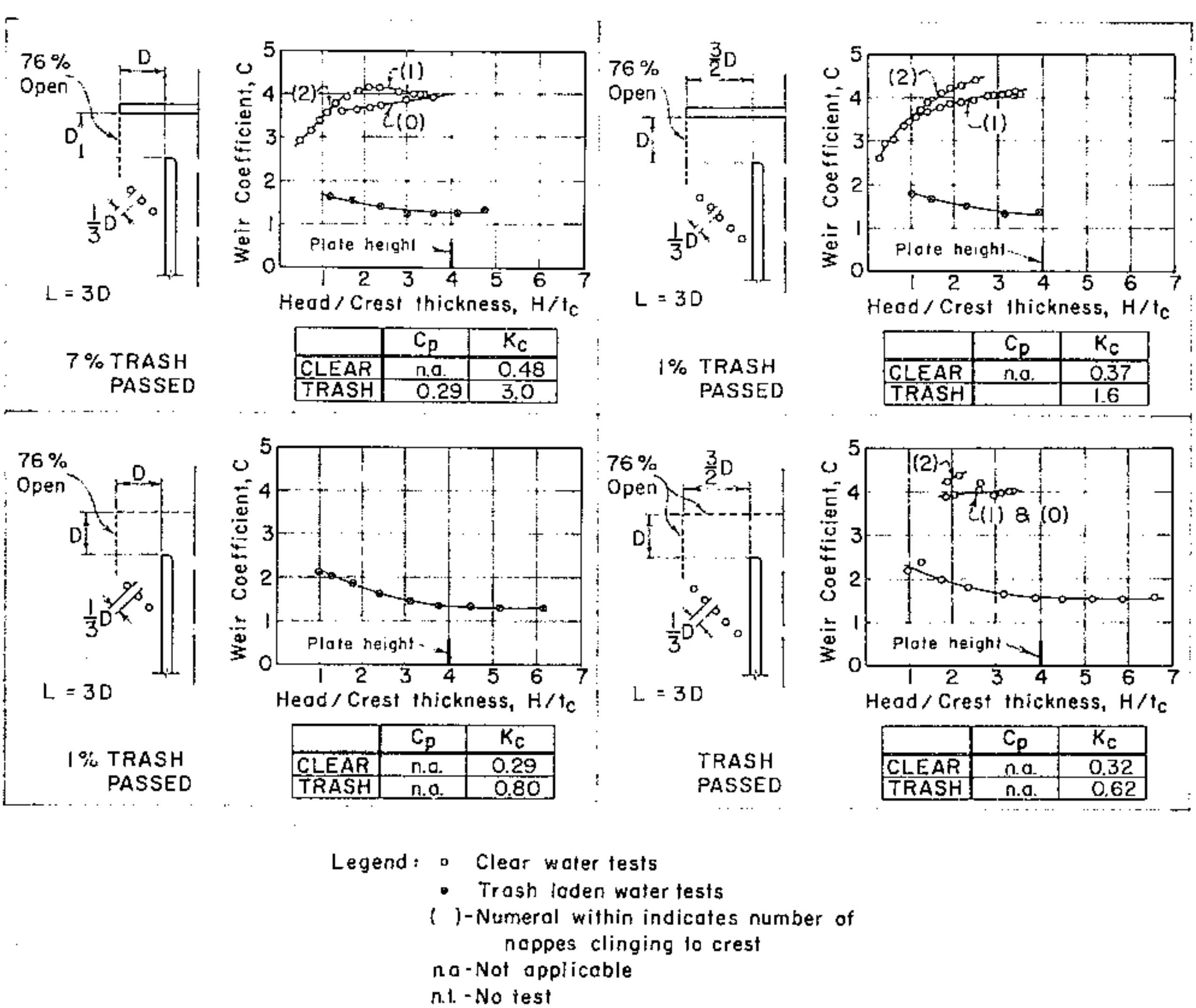


FIGURE 33.—Results of flexible-trash tests on two-way drop inlets $3D$ long, with D plate height and with mesh side for solid and open mesh plates and for plate overhangs of D and $3D/2$.

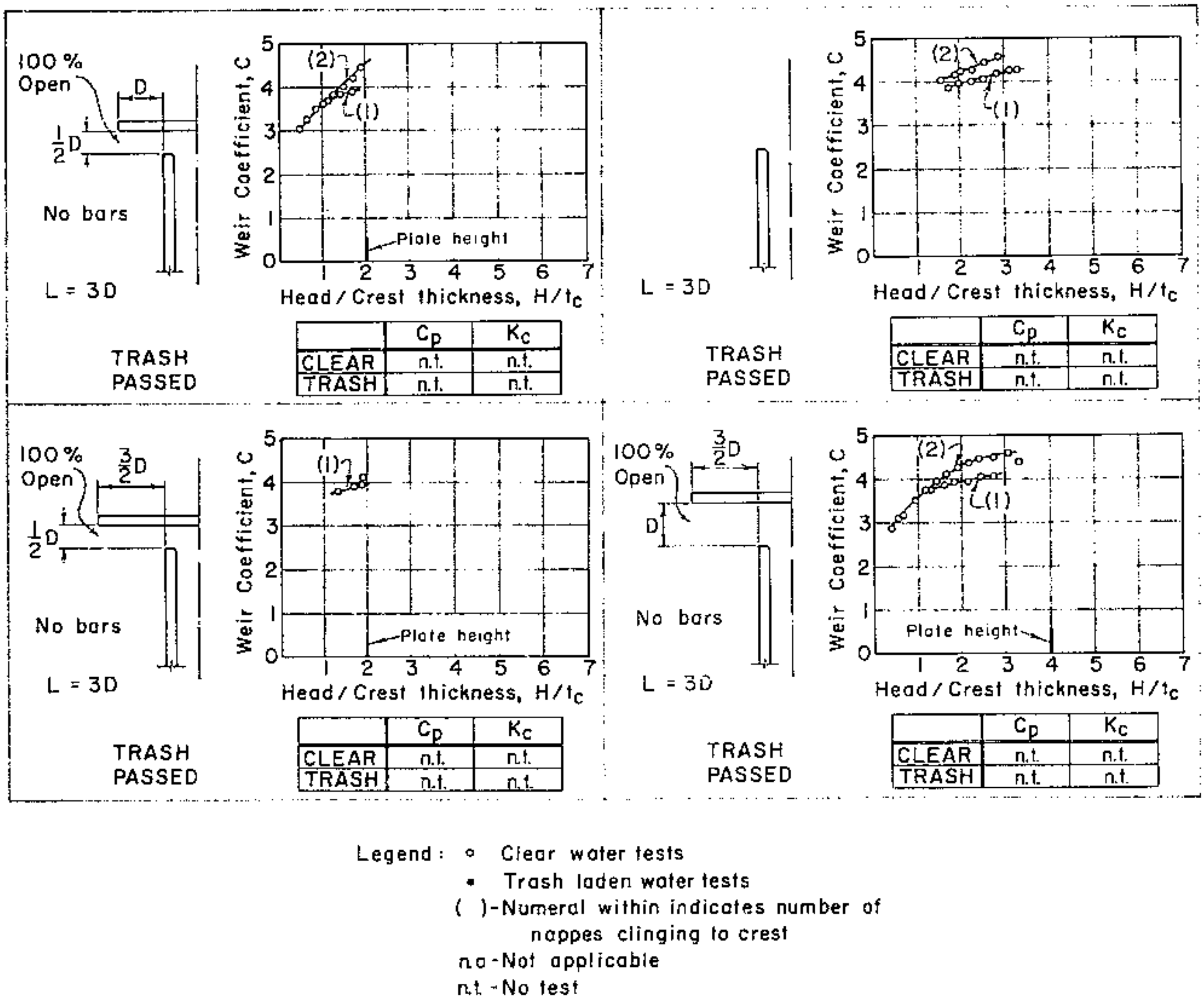


FIGURE 34.—Results of flexible-trash tests on two-way drop inlets 3D long without trash racks.

in the field since the start of the 2D-long drop inlet tests. Structures with open mesh plates attracted proportionately more flexible trash to the plate and side vents than to the rack base. In contrast, structures with solid plates attracted trash mainly to the rack bars where water currents were strongest. Typical before and after photographs, figures 35 and 36, illustrate dramatically the difference between trash accumulation patterns for solid and open mesh plates.

The effect of plate type, solid or mesh, on the head-discharge relationship for the structure is determined by comparing flow-coefficient values. Crest-loss coefficients were averaged for all racks tested to obtain the values given in table 10.

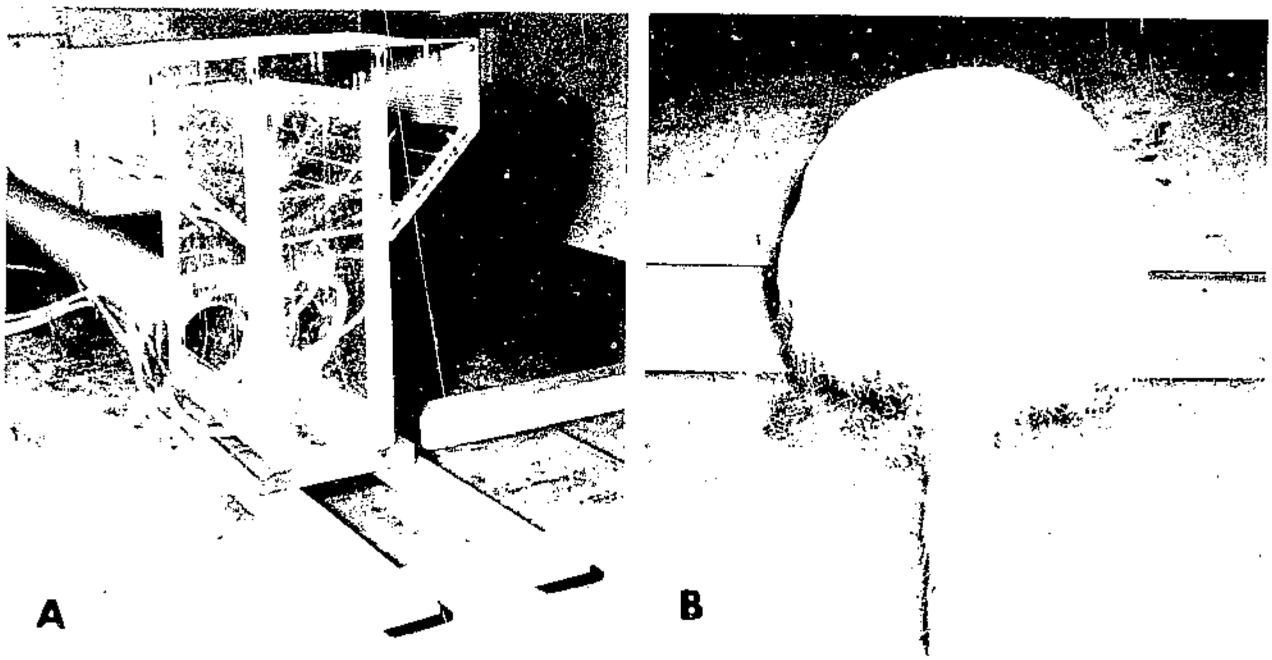
TABLE 10.—*Average crest-loss coefficients, K_c*

Plate	Flow	Z_p	
		D/2	*D*
Solid	Clear	1.2	0.45
Do.	Trash	5.0	2.6
Mesh	Clear	.42	.34
Do.	Trash	1.6	.74

The table shows a smaller coefficient (less head loss) for the mesh plate than for the solid plate. All flow must go around and under the

PN—3616, PN—3617

FIGURE 35.—The 3*D*-long two-way drop inlet with solid deck before (*A*) and after (*B*) standard flexible-trash test.



PN—3618, PN—3619

FIGURE 36.—The 3*D*-long two-way drop inlet with open mesh plate before (*A*) and after (*B*) standard flexible-trash test.

solid plate; therefore, head loss is greater than for the mesh plate, which some of the flow can pass through.

Weir coefficients, ranging from 3.6 to 4.1 for clear water tests, depending upon the head chosen for comparison, were not affected by the type of plate. For trash-laden flows the weir coefficient was higher with the mesh plate than with the solid plate. The average values for the two plates were 1.6 and 1.2, respectively.

The drop inlet with the solid plate probably had a smaller weir coefficient because more

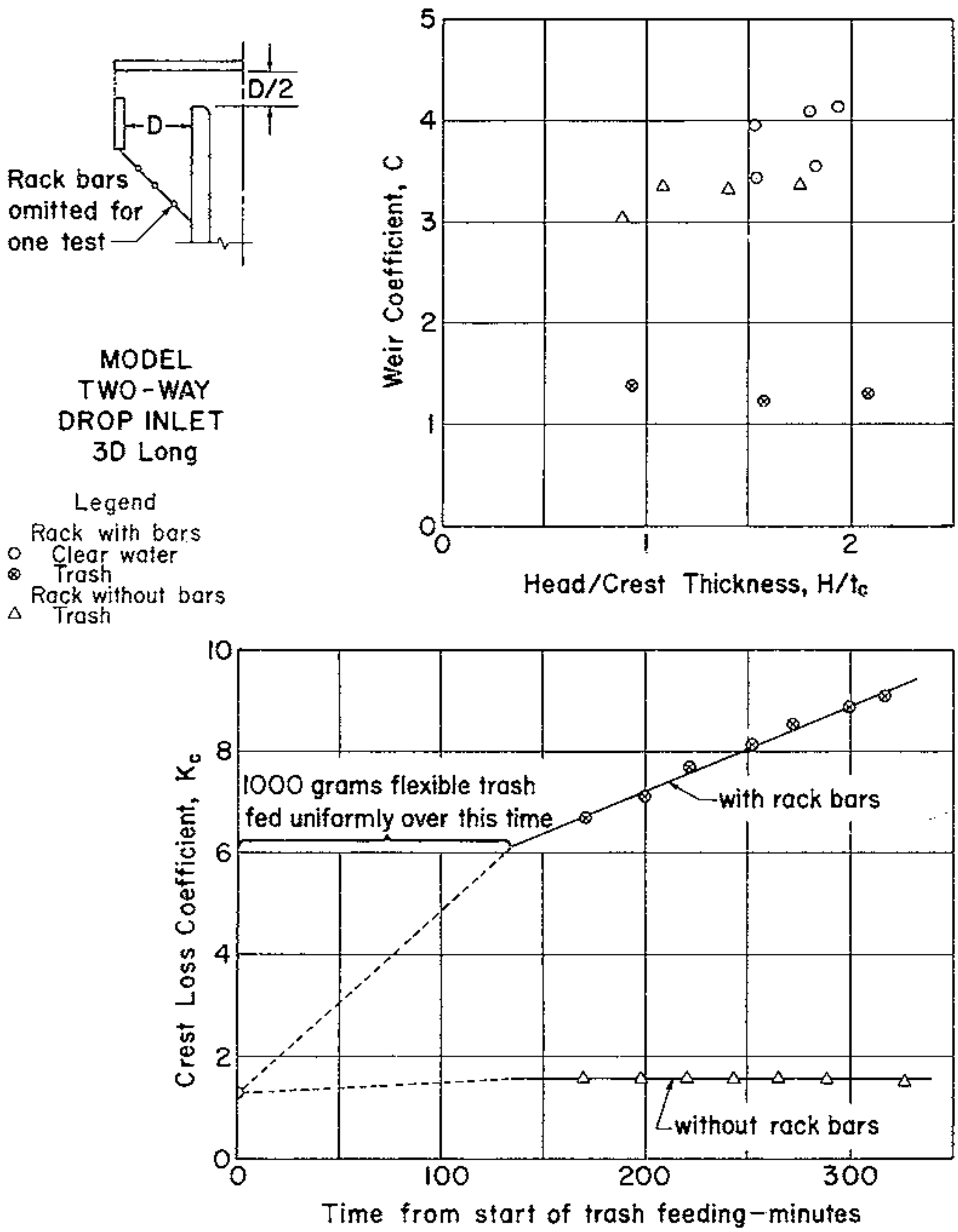


FIGURE 37.—Weir coefficients and entrance loss coefficients compared for tests on a two-way drop inlet with and without rack bars on the trash rack.

trash accumulated on its rack bars than on the mesh plate of the other drop inlet. Evidently, for the mesh-plate-equipped drop inlet, more of the trash accumulated on top of the plate, leaving less to lodge on the rack bars.

The effect, on flow of the side panel, whether skirt or mesh, is indicated by the flow-coefficient values. Average values of the crest-loss coefficients are given in table 11.

The more open racks with mesh plates and sides have the lower loss coefficients.

The weir-flow coefficients for two side panel styles are compared in table 12.

For trash-laden flows the more open racks have higher weir coefficients, but the differences are probably not significant.

Omitting the bars on the underside of the trash rack on the two-way drop inlet had a significant effect. This was done in one test. Figure 37 shows

TABLE 11.—*Average crest-loss coefficients*

Side panel	Flow	Plate	
		Mesh	Solid
Skirt	Clear	0.40	0.86
Do.	Trash	1.2	4.2
Mesh side	Clear	.36	.83
Do.	Trash	1.1	3.4

TABLE 12.—*Average weir coefficients*

Side panel	Flow	Plate	
		Mesh	Solid
Skirt	Clear	3.7	3.8
Do.	Trash	1.4	1.1
Mesh side	Clear	3.9	4.0
Do.	Trash	1.6	1.4

weir coefficients and crest-loss coefficients measured during this test. The weir capacity for the trash flow is 94 percent of that for clear water and K_c for trash flow is only 18 percent greater than the clear water value. That there was any capacity reduction at all was the result of some trash fibers wrapping around the end walls and the solid skirt. During this test 46 percent of the total trash load passed through the structure.

Another significant effect is illustrated in figure 37. K_c for the test without bars on the rack did not change with time after the end of feeding. Probably the greater part of the flow passed through the unobstructed area between the inside of the skirt and the outside of the drop inlet. Since there was no flexible trash in this flow path, there could be no accumulation of sediment to affect the K_c value.

THE SOIL CONSERVATION SERVICE STANDARD TRASH RACKS

Three trash racks proposed by the Soil Conservation Service as standards were tested. These are identified as racks 1, 3, and 5, and are shown on figures 38, 52, and 68, respectively. Laboratory modifications to the standard designs—racks 1 (high), 2 and 2a, 3a and 3b, and 4—shown on figures 38, 44, 52, and 64, were also tested. Models and prototypes of these racks were investigated. Both flexible and rigid trash was used in the tests but not on all structures. Table 13 lists the tests performed on each rack.

Racks 1 and 1 (High)

Rack 1 (fig. 38) was intended for use on drop inlets with sediment deposits up to their crests. This extent of sediment fill could not be reproduced at reasonable cost in the full-size reservoir, so the prototype rack was tested on the available full-size drop inlet which projects about 6 feet above the reservoir floor. The model installation simulated this projected condition. Standard rigid-trash tests were run on both the prototype and the model. The rigid-trash distribution pattern for the model and prototype (figs. 39 and

TABLE 13.—*Trash tests performed on standard and modified Soil Conservation Service racks*

Rack	Model		Prototype	
	Flexible	Rigid	Flexible	Rigid
Standard:				
1	...	x	...	x
3	x	x	...	x
5	x	x	...	x
Modified:				
1 (high)	x	...	...	...
2	...	x	...	x
2a	x	x	x	x
3a	...	x	...	x
3b	...	x	...	x
4	...	x	...	x

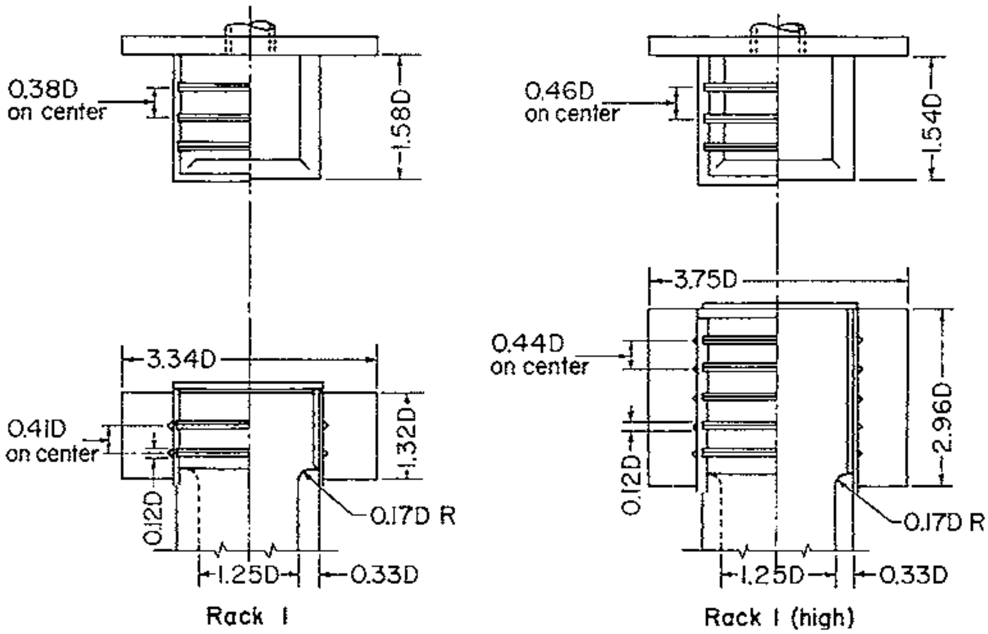


FIGURE 38.—The proportions of the three-way square drop inlets, racks 1 and 1 (high).

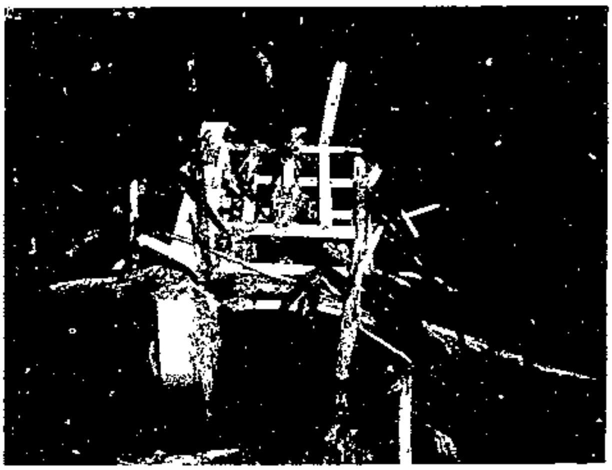
40) are similar, but more sticks are lodged in the model rack than in the prototype.

The weir coefficients for the model and the prototype for clear water and rigid-trash tests are plotted in figure 41. Agreement of the model values with those of the prototype is good for both the clear water and the trash tests. Crest-loss coefficients from these tests are given in table 14. For the rigid-trash tests, the K_c value is much larger for the model than the prototype. Apparently the larger amount of trash lodged in the model rack is responsible for the larger value of K_c.

Since it appeared that the open area of rack 1 would be too small for expected flexible-trash accumulations, a taller rack with more open area was designed for the model. This rack, shown in figure 38, is designated as rack 1 (high).

PN—3620

FIGURE 39.—After standard rigid-trash model test on rack 1 (inlet in reservoir).



PN—3621

FIGURE 40.—After standard rigid-trash prototype test on rack 1 (inlet in reservoir).

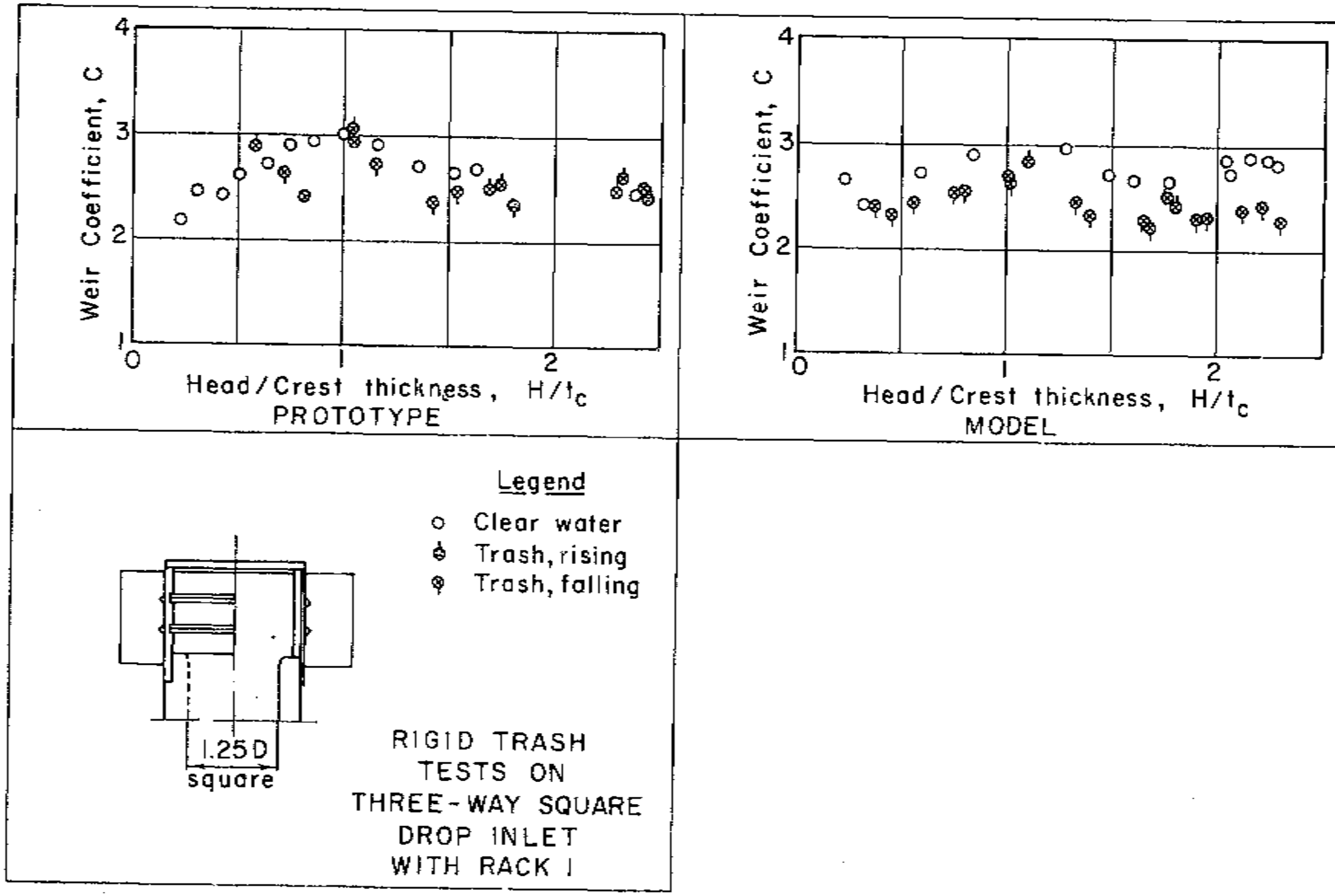


FIGURE 41.—Weir coefficients for clear water and rigid-trash flow tests on model and prototype of a three-way square inlet with rack 1.

The model drop inlet on which rack 1 (high) was installed simulated an installation in the face of a dam, with the crest level with a horizontal berm. This configuration simulated a sediment-filled reservoir, the condition for which rack 1 was originally designed. A clear water test and a standard flexible-trash test were run on this model. Model rack 1 (high) is shown in figure 42. Weir coefficients are plotted in figure 43.

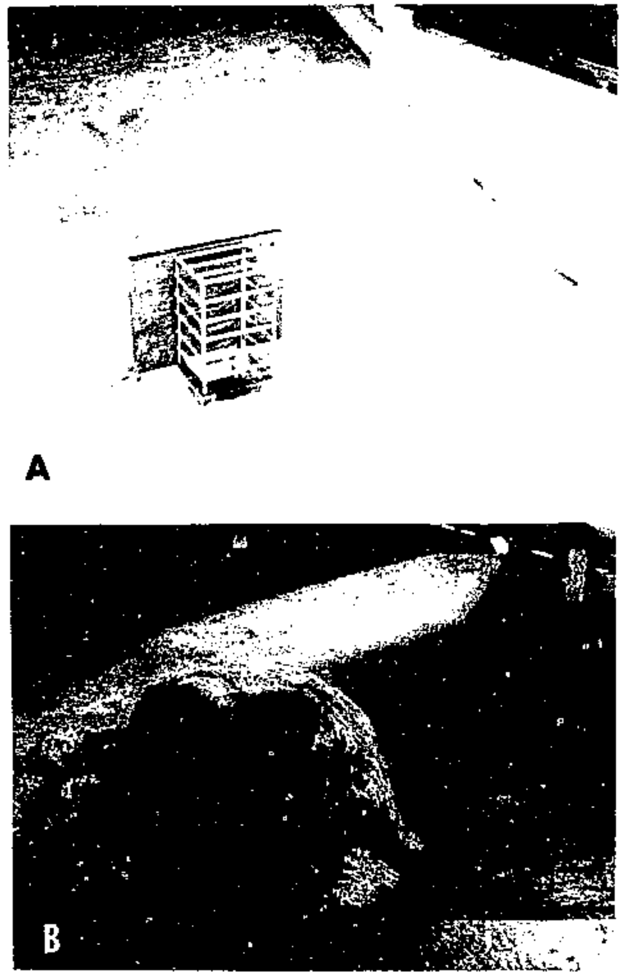
The weir coefficients for the clear water tests were similar for rack 1 (high) and for rack 1. For the flexible-trash tests the weir coefficient for rack 1 (high) dropped to 0.17, representing a 19-fold reduction in weir-flow capacity. The crest-loss coefficients increased from 0.21 for clear water tests to 1.5 for the trash tests. All values are given in table 14.

Racks 2 and 2a

Rack 2 has rack bars across the top like rack 1 and is the same height, but the three sides of rack 2 are placed outside the drop inlet sides and have open mesh panels that partly cover the sides and extend slightly below the level of the drop inlet crest. Rack 2 has no horizontal rack bar near the level of the crest, as rack 1 does. Rack 2a is a minor variation of rack 2 in that the mesh panels cover the entire sides. Details of racks 2 and 2a are shown in figure 44.

Racks 2 and 2a were tested with rigid trash on both the model and the prototype drop inlets, and rack 2a, with flexible trash. Figures 45 and 46 show the model and prototype of rack 2 after a rigid-trash test. Figures 47 and 48 show similar views of rack 2a. The similar appearance of the model and the prototype of both racks is striking.

The weir coefficients for rack 2 for clear water and trash tests are shown in figure 49. The model and prototype values of C are very close for clear water flows. Rigid trash in the rising stage of flow caused no decrease from the clear water C values, but in the falling stage the C values were



PN—3622, PN—3623

FIGURE 42.—Model of standard trash rack 1 (high) with rack and inlet in dam face before (*A*) and after (*B*) standard flexible-trash tests.

TABLE 14.—*Test results for three-way square drop inlet rack 1*

Test scale	Trash load[1]	Weir coefficient, C		Crest-loss coefficient, K_c		Trash passed (percent)
		Clear water	With trash	Clear water	With trash	
Model	Rigid	3.0	2.5	0.30	2.2	21
Do.	Flexible[2]	3.0	.17	.21	1.5	32
Prototpe	Rigid	3.0	2.6	.19	.60	24

[1] All standard loads.

[2] High rack and inlet in dam face.

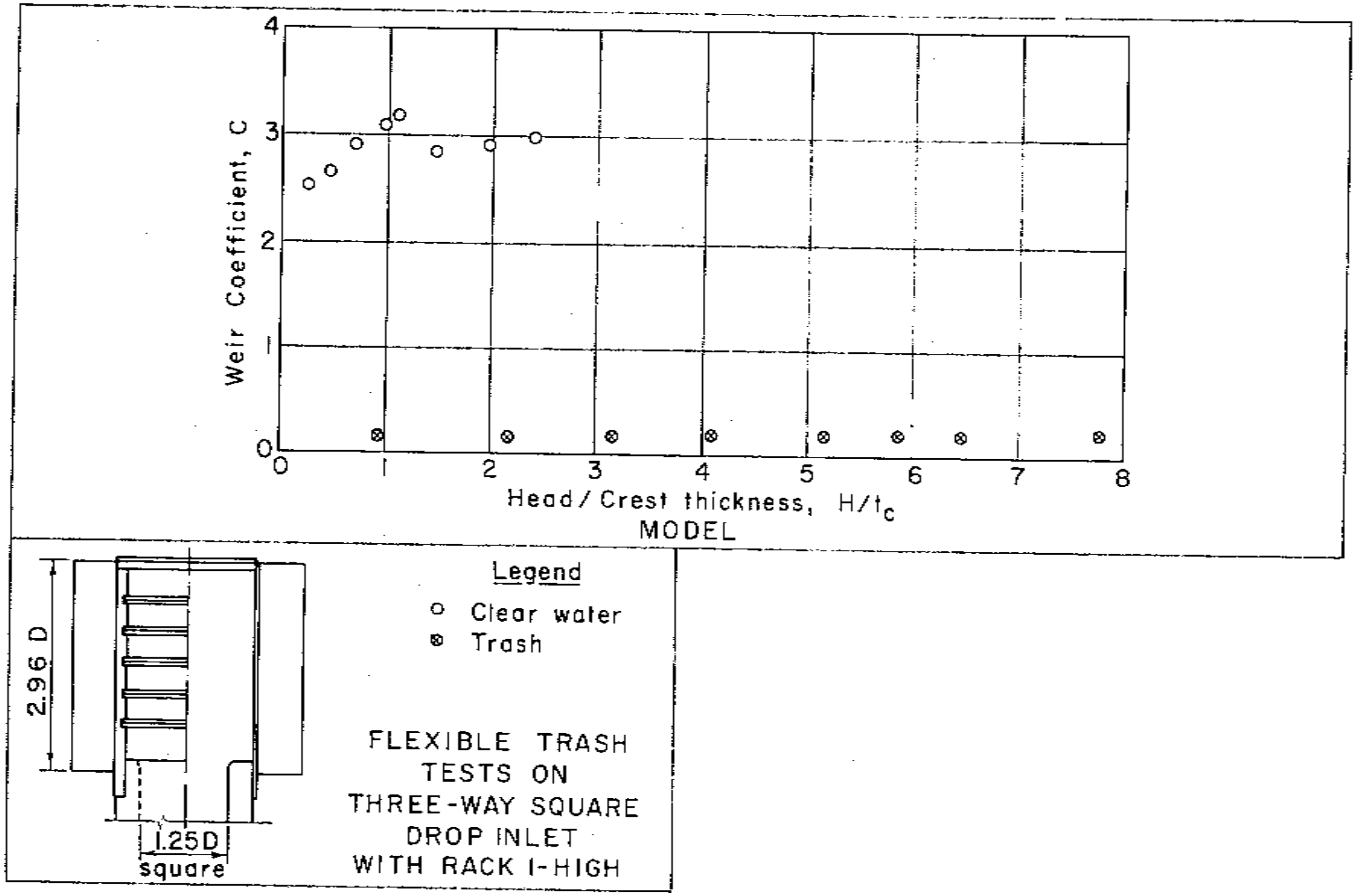


FIGURE 43.—Weir coefficients for clear water and flexible-trash flow tests on the three-way square drop inlet model with the high rack.

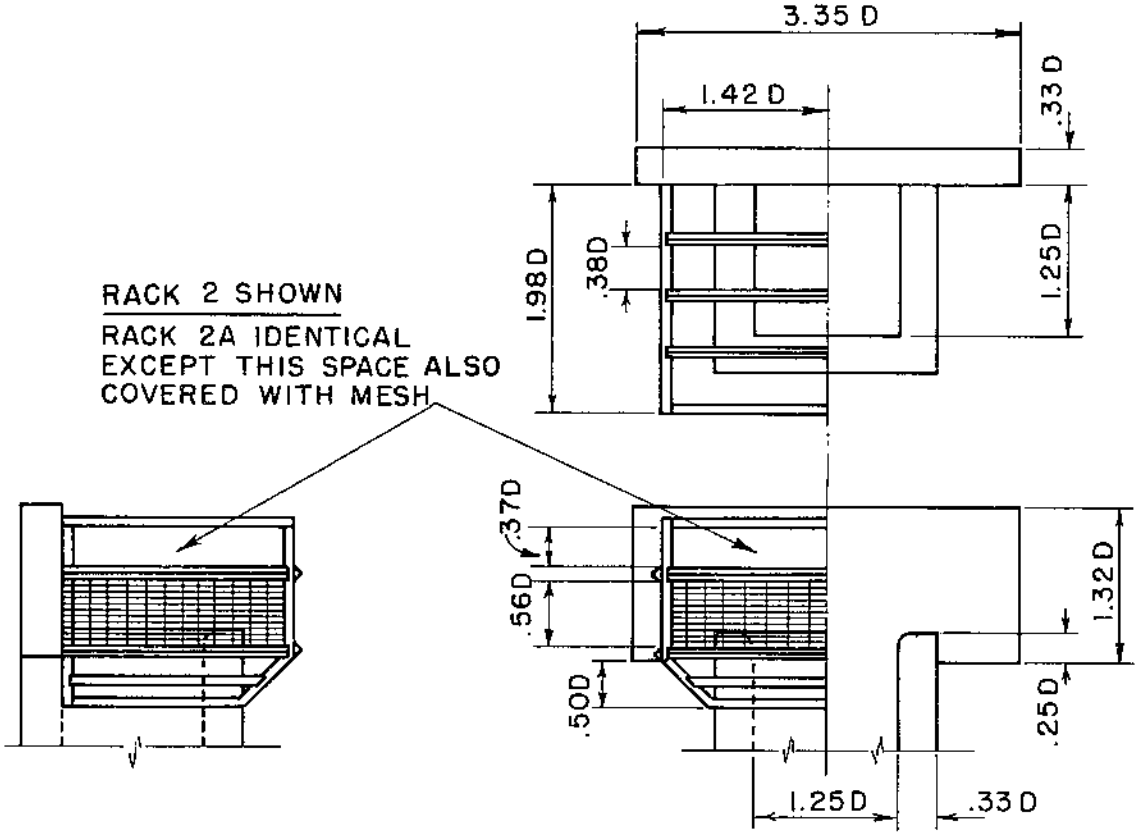
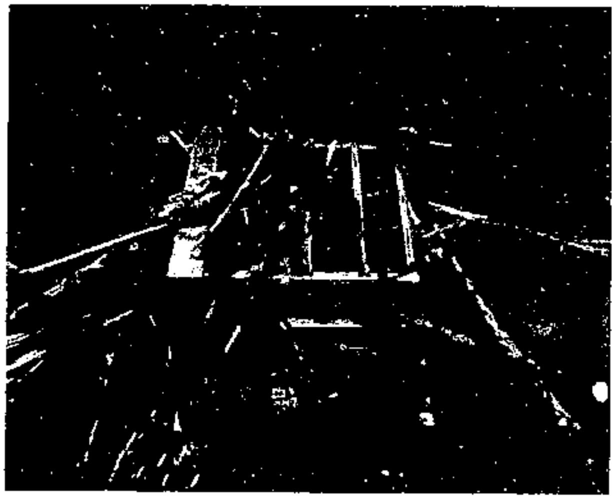
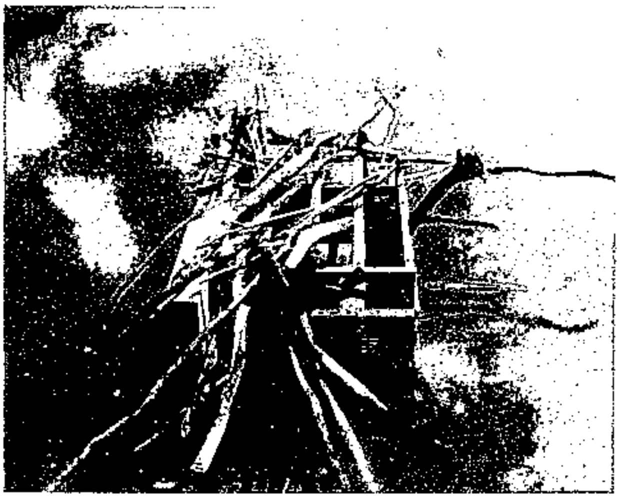


FIGURE 44.—The proportions of the laboratory-modified trash racks for the three-way square drop inlet, racks 2 and 2a.



PN—3624
FIGURE 45.—After standard rigid-trash model test on rack 2.

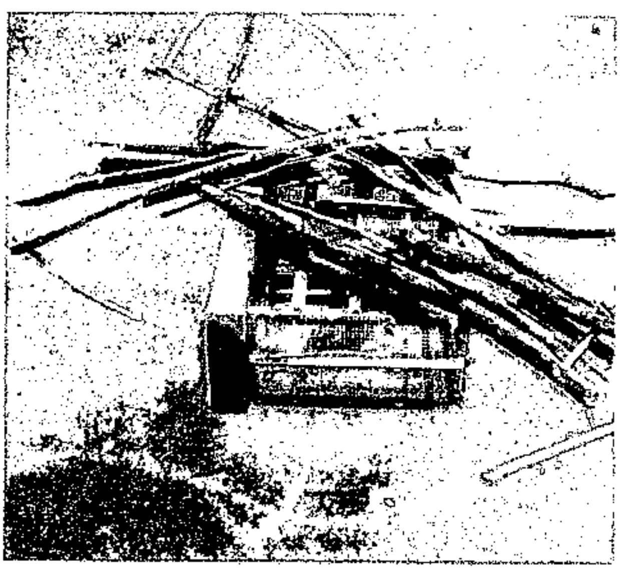


PN—3625
FIGURE 46.—After standard rigid-trash prototype test on rack 2.

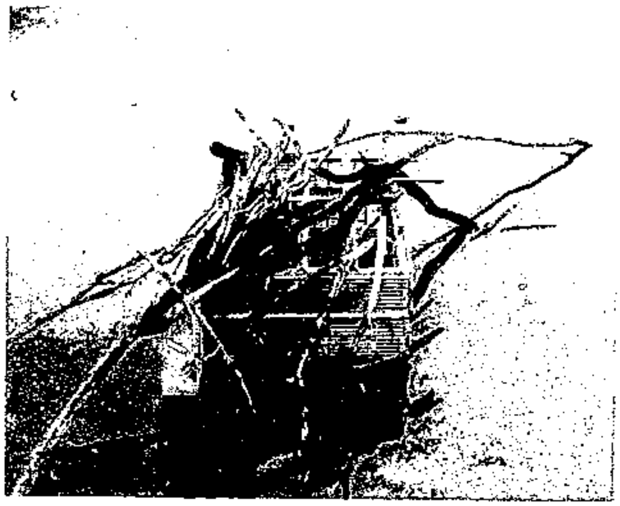
reduced by the trash. As shown in figures 45 and 46, sticks lodged in the racks and some entered the drop inlet. Evidently the accumulation occurred during pipe flow, and the sticks were in position to interfere with the weir flows during the falling stage.

Weir coefficients for rack 2a in the rigid-trash tests are shown in figure 50. Model and prototype values are alike for clear water flow and for both the rising and falling stages of rigid trash-laden flows. There was no reduction in C caused by the trash. As shown in figures 47 and 48, the mesh sides were effective and practically no sticks entered the rack. However, these sides intercepted flexible trash, which reduced the weir coefficient. The coefficients for the flexible-trash tests on rack 2a are shown in figure 51.

Crest-loss coefficients for racks 2 and 2a are given in table 15 along with weir coefficients and data on the amount of trash passing through the structure. The clear water crest-loss coefficients for racks 2 and 2a are identical, and the model values are in close agreement with the prototype values. Trash in the flow increased the crest-loss coefficient in all instances, but in rack 2 rigid-trash tests, the model showed a greater increase in K_c than the prototype. For rack 2a flexible-trash tests the results were reversed, with the prototype showing a greater percentage increase in K_c than the model. The reasons for this inconsistency are not clear; probably they are related to the particular trash accumulation patterns on the racks.



PN–3626
FIGURE 47.—After standard rigid-trash test on model rack 2a.



PN–3627
FIGURE 48.—After standard rigid-trash test on prototype rack 2a.

Racks 3, 3a, and 3b

Rack 3 was designed for drop inlets in open water or in sediment-filled reservoirs. The open area through the sides and top of the rack was designed to be sufficient if the bottom openings should be closed by sediment. Details of rack 3 and its two variations, 3a and 3b, are shown in figure 52.

The racks were tested in open water only. A flexible-trash test on the model of rack 3 resulted in a large accumulation of trash on the rack (fig. 53). The weir coefficient was reduced from 3.50 for clear water to 1.50 for the trash-covered rack, and the crest-loss coefficient was increased from 0.34 to 1.82 (table 16).

The center wall was removed from the model for the rigid-trash tests because the prototype did not have a center wall. Views of the model and the prototype of rack 3 after rigid-trash tests are shown in figures 54 and 55, respectively. Sticks have entered the racks and accumulated on the tops. Weir-flow coefficients for the clear water and the rigid-trash tests for both the model and prototype are plotted in figure 56. The maximum values of the weir coefficient are given in table 16 along with crest-loss coefficients.

Removal of the center wall increased the weir coefficient for clear water flow from 3.50 to 4.10.

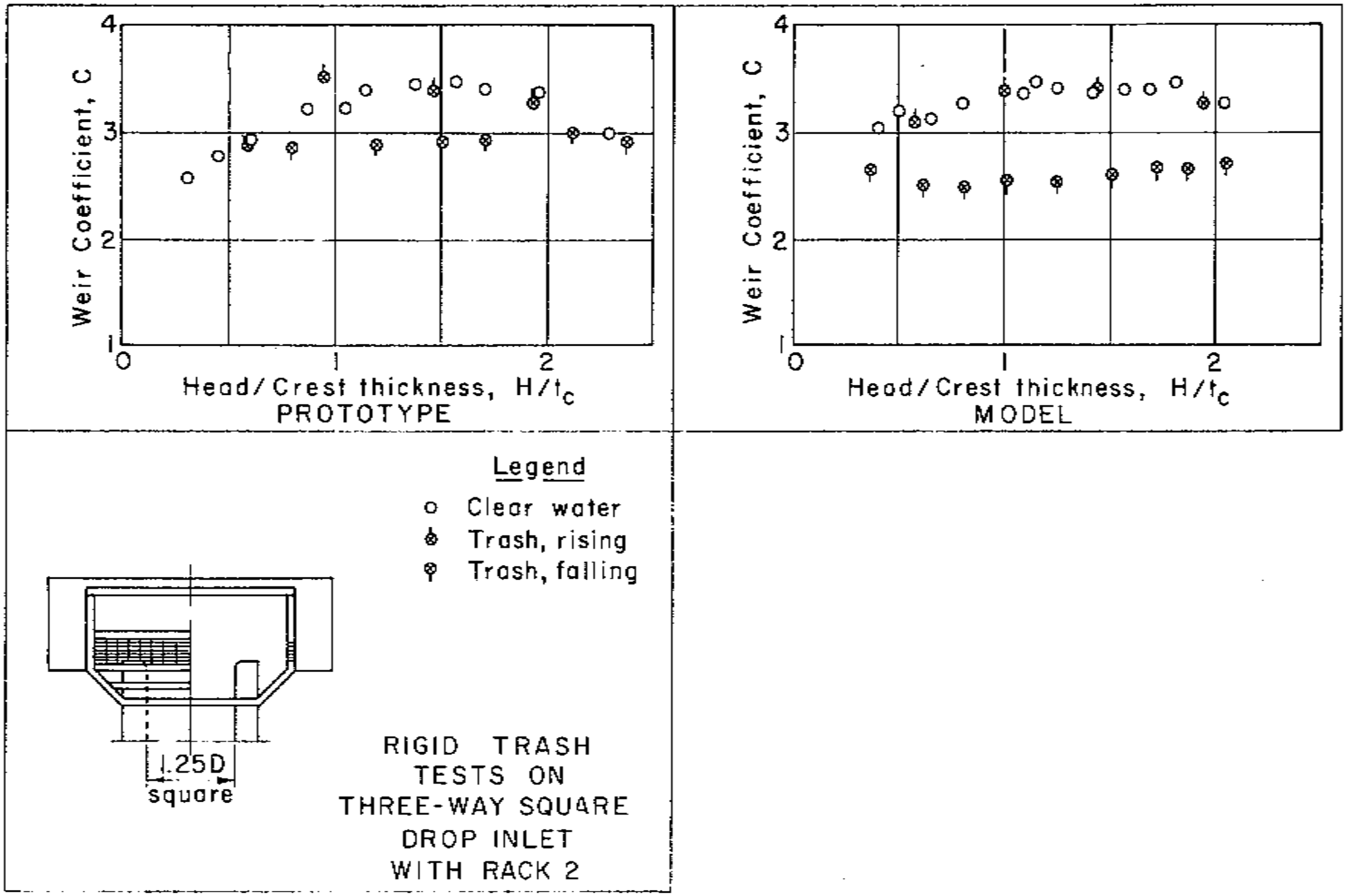


FIGURE 49. —Weir coefficients for the three-way square drop inlet with a laboratory-modified trash rack, rack 2, for rigid-trash tests on models and prototype structures.

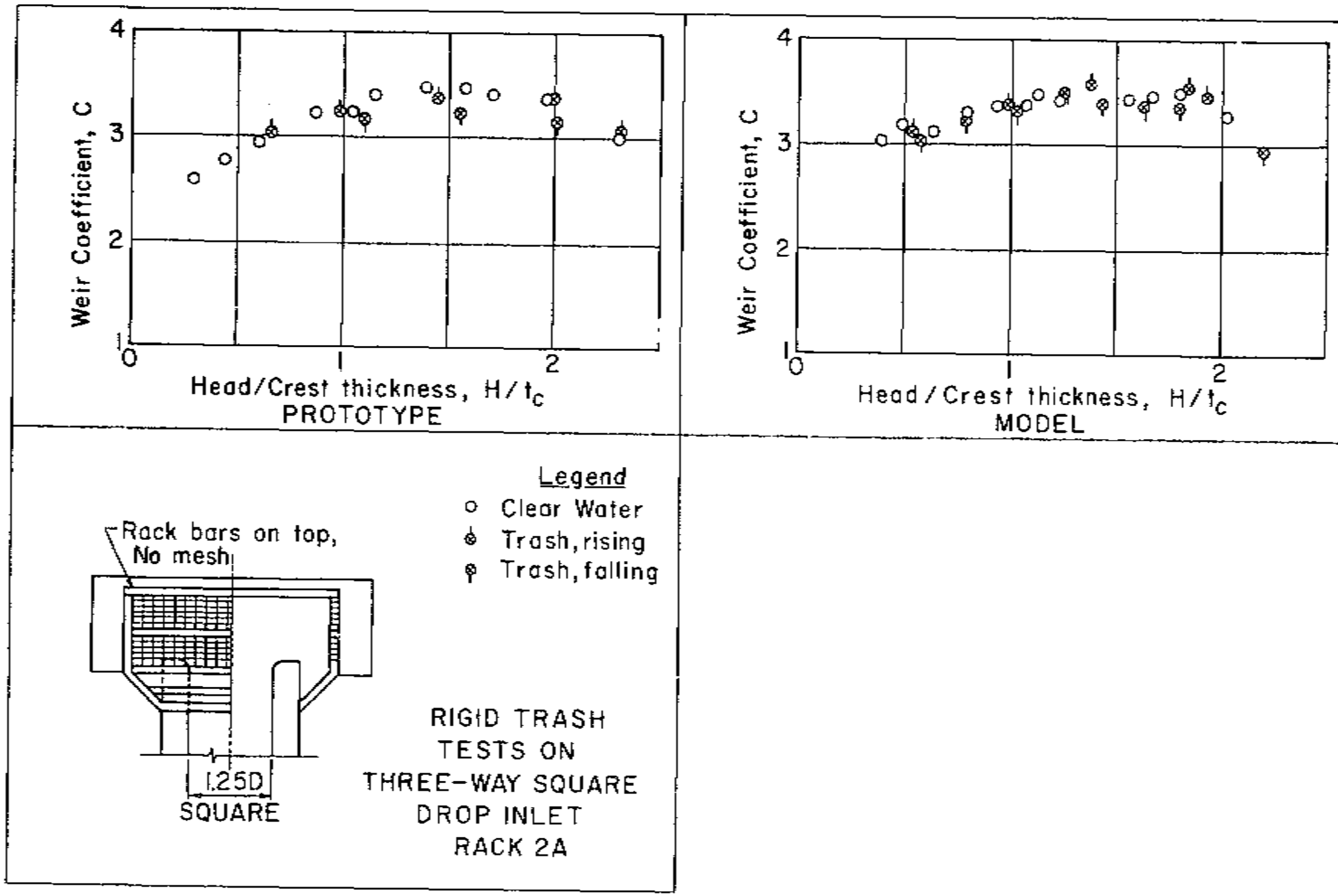


FIGURE 50.—Weir coefficients for the three-way square drop inlet with a laboratory-modified trash rack, rack 2a, for rigid-trash tests on models and prototype structures.

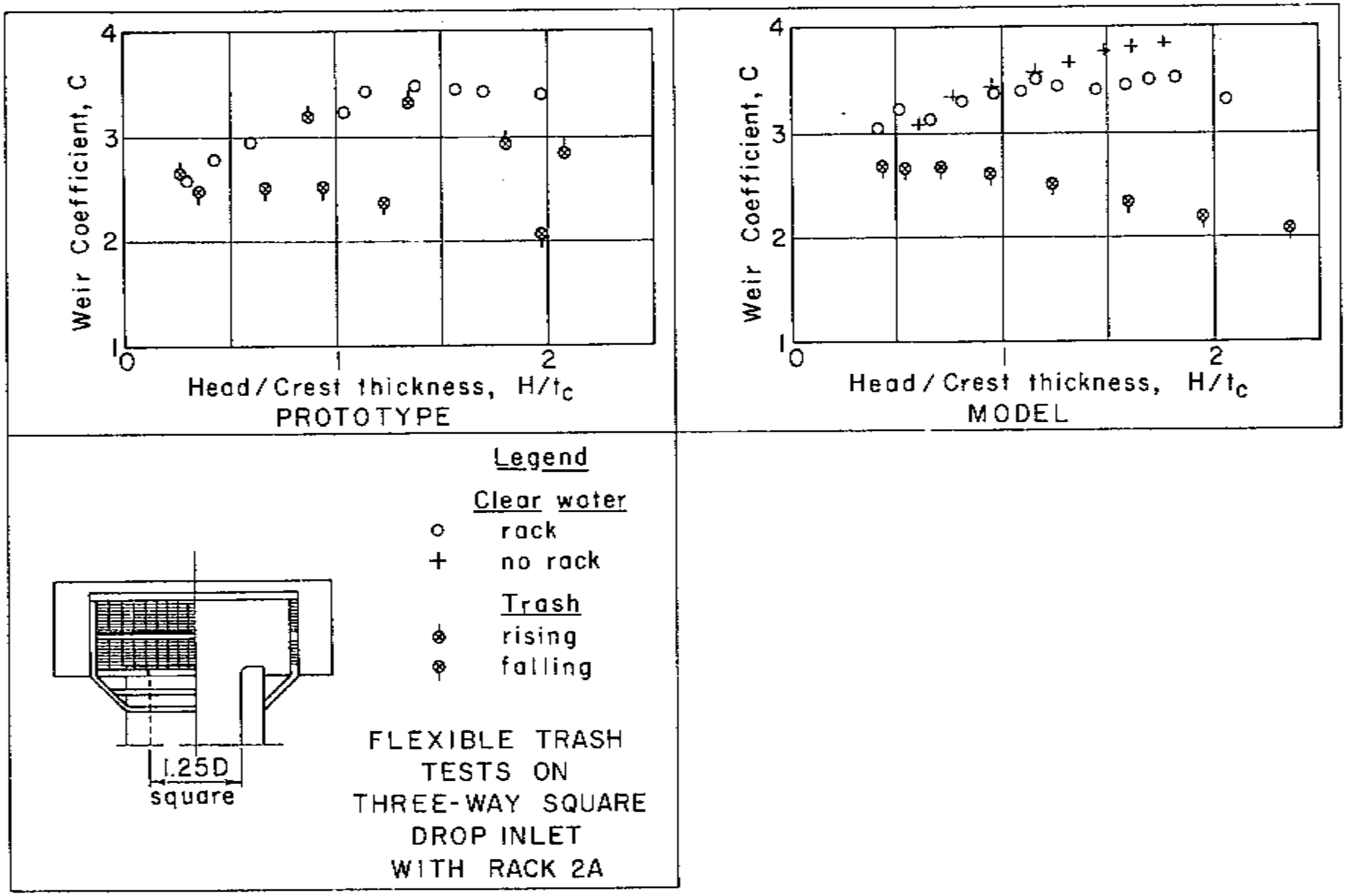


FIGURE 51.—Weir coefficients for the three-way square drop inlet with a laboratory-modified trash rack, rack 2a, for flexible-trash tests on models and prototype structures.

TABLE 15.—*Test results for three-way square drop inlet, racks 2 and 2a*

Test scale	Rack	Trash load[1]	Weir coefficient, C		Crest-loss coefficient, K_c		Trash passed (percent)
			Clear water	With trash	Clear water	With trash	
Model	2	Rigid	3.45	2.6	0.30	1.81	28
Do.	2a	do.	3.45	3.40	.30	.39	13
Do.	2a	Flexible	3.45	2.35	.30	.55	4
Prototype	2	Rigid	3.47	2.9	.28	.76	35
Do.	2a	do.	3.47	3.25	.28	...	...
Do.	2a	Hay (1 large truckload).	3.47	2.25	.28	1.31	...

[1] All standard unless otherwise indicated.

The true crest length (center wall thicknesses deducted) was used in calculating the coefficient. The center wall probably disturbed the flow, causing the nappe to spring free and reducing the weir coefficient.

Weir coefficients for the rack 3 model were very close to those for the prototype (fig. 56) in the clear water flows. The presence of rigid trash reduced the weir coefficients more for the model than for the prototype. Also, the coefficients for flows on the rising stage were about like those on the falling stage. Evidently the sticks responsible for lowering the coefficient entered the rack early in the test.

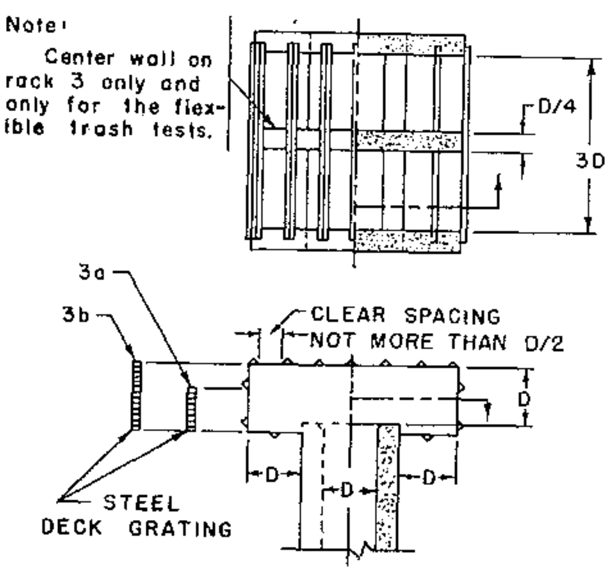
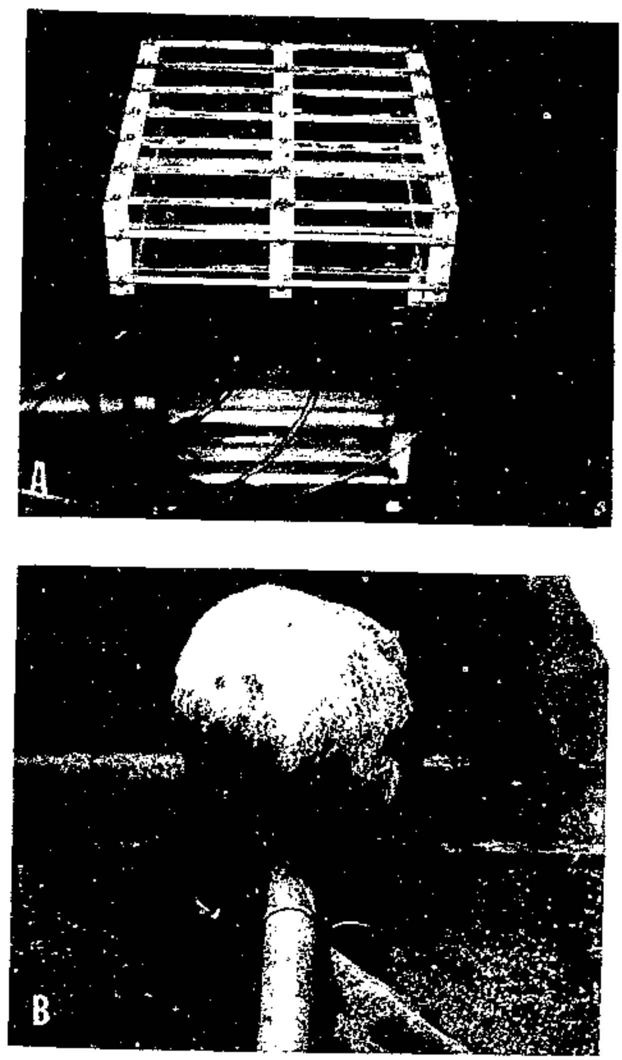


FIGURE 52.—The two-way drop inlet with standard trash rack 3, and laboratory modifications, racks 3a and 3b.



PN—3628, PN—3629

FIGURE 53.—Model of standard trash rack 3 before (*A*) and after (*B*) standard flexible-trash test.

TABLE 16.—*Test results for two-way drop inlet, 3D-long racks 3, 3a, and 3b*

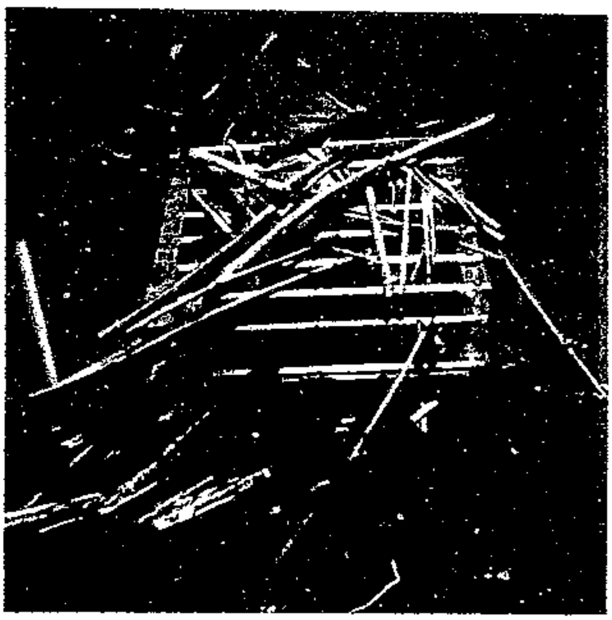
Test scale	Rack	Trash load[1]	Weir coefficient, C		Crest-loss coefficient,[2] K_c		Trash passed (percent)
			Clear water	With trash	Clear water	With trash	
Model	[3]3	Flexible	3.50	1.50	0.34	1.82	11
Do.	3	Rigid	4.10	3.40	.34	1.3	27
Do.	3a	do.	4.10	3.86	.34	.47	10
Do.	3b	do.	4.10	4.0	.34	.46	3
Prototype	3	do.	3.90	3.5	.31	1.1	42
Do.	3a	do.	3.90	3.75	.31	.57	43
Do.	3b	do.	3.90	3.8	.31	.50	3

[1] All standard loads.
[2] Entrance-loss coefficients determined by weighting 6 piezometers at riser midheight.
[3] Splitter wall used.

The crest-loss coefficients for the model and the prototype were much alike for both the clear and trash flows (table 16). The trash in and on the rack increased the crest-loss coefficient to about 3.5 times its clear water value.

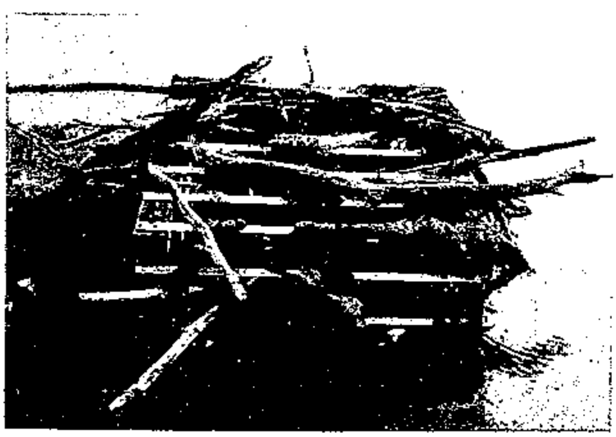
To reduce the number of sticks entering the rack, a partial-height mesh side panel was added to rack 3. This variation is identified as rack 3a. Weir-flow coefficients for clear water and rigid-trash flows on both the model and the prototype of rack 3a are shown in figure 57. Weir coefficients given in table 16 are the maximum values for clear water tests. Values for the trash tests are for the same head in which the maximum clear water values occurred. Crest-loss coefficients are average values for clear water and trash tests. The partial mesh side panel improved the performance of the rack; the changes in the coefficients over the clear water values are less for rack 3a than for rack 3. This is attributed to the lodging of fewer sticks in rack 3a (figs. 58 and 59) than in rack 3.

Since the partial-height mesh side panel proved effective in keeping trash out of the drop inlet, a full-height mesh side panel (rack 3b) was tried to see if performance could be further improved. Rigid-trash tests on rack 3b showed the



PN-3630

FIGURE 54.—After standard rigid-trash model test on rack 3.



PN-3631

FIGURE 55.—After standard rigid-trash prototype test on rack 3.

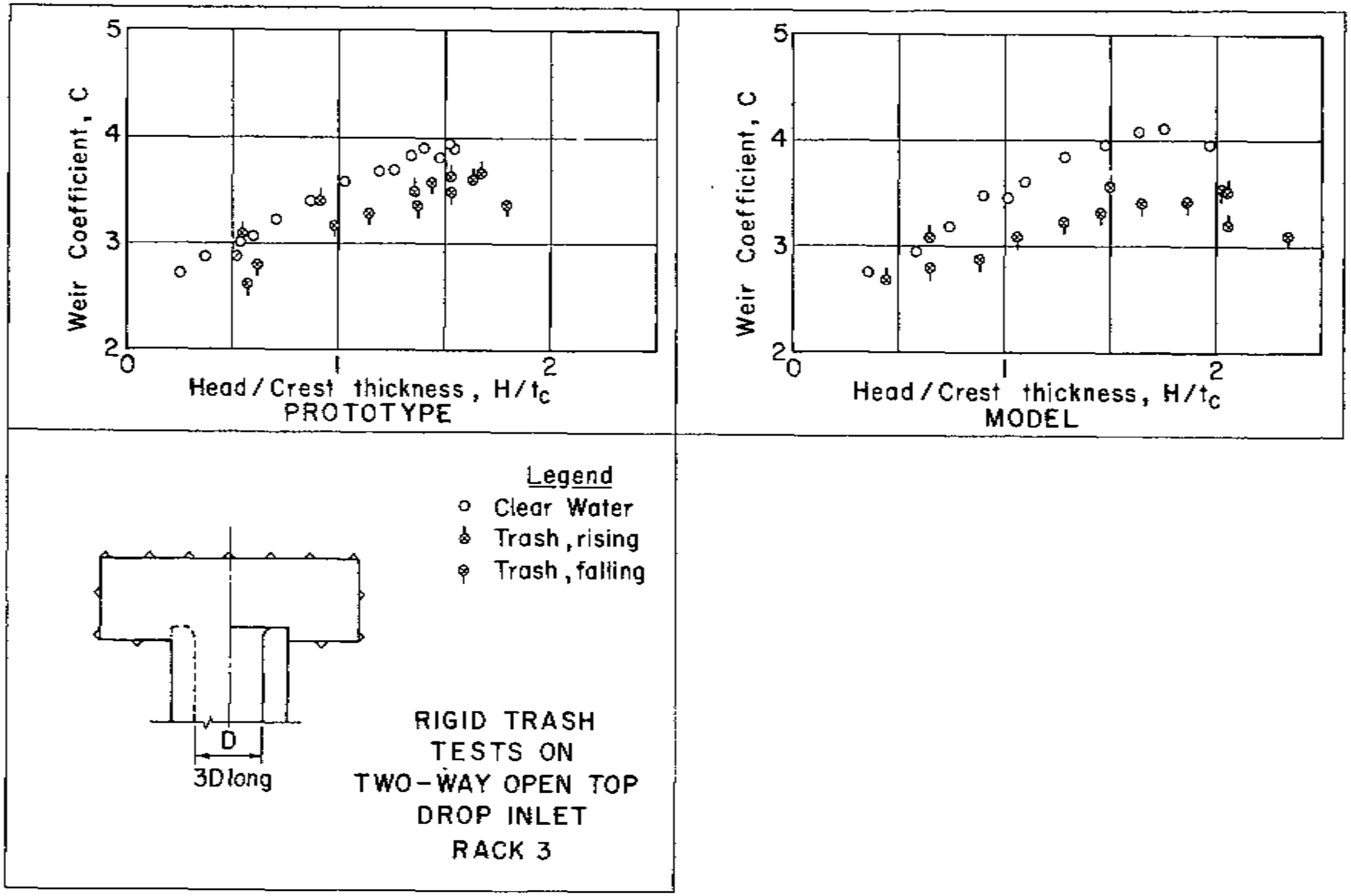


FIGURE 56.—Weir coefficients and head-discharge relations for rigid-trash tests on trash rack 3.

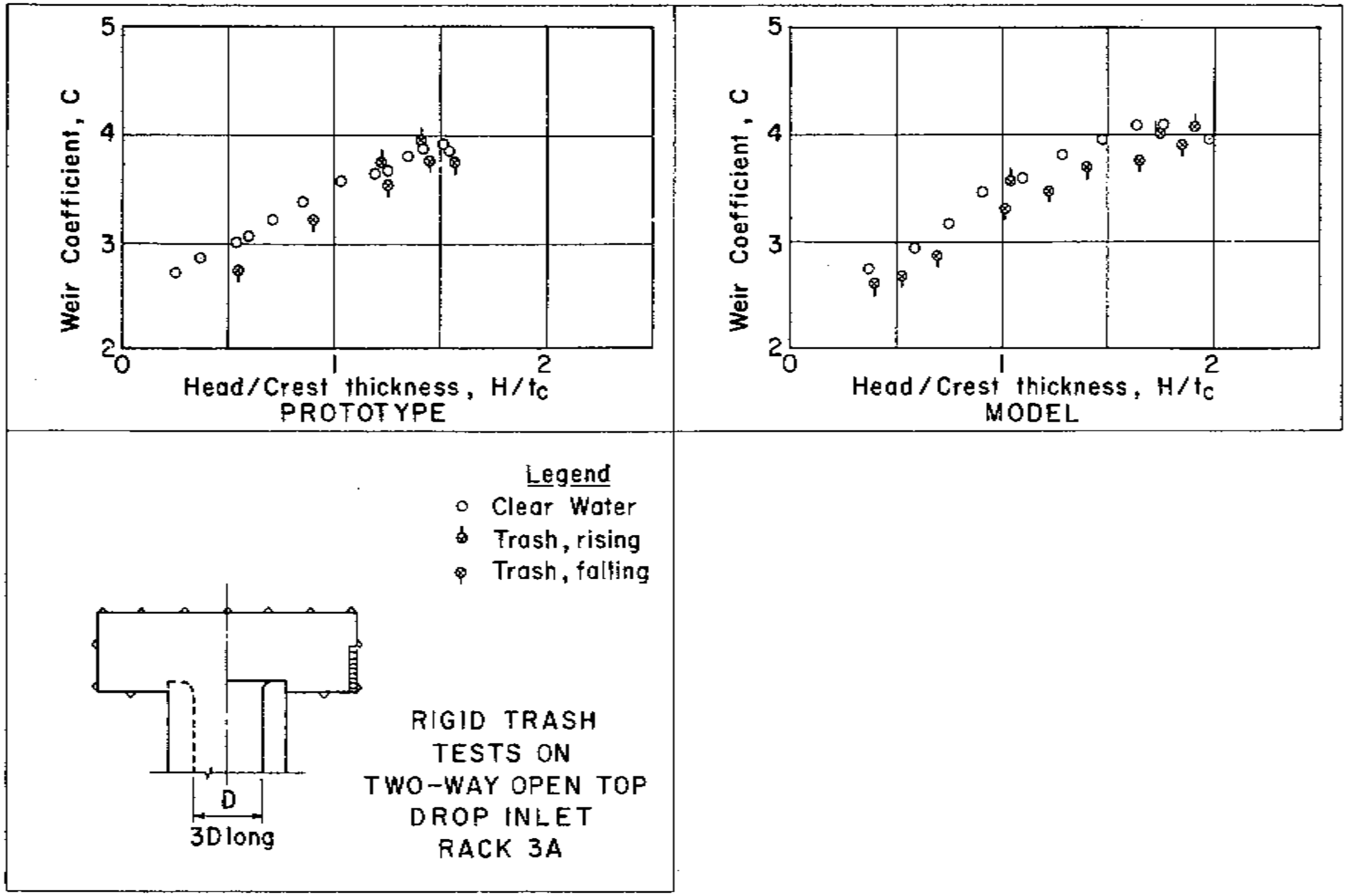
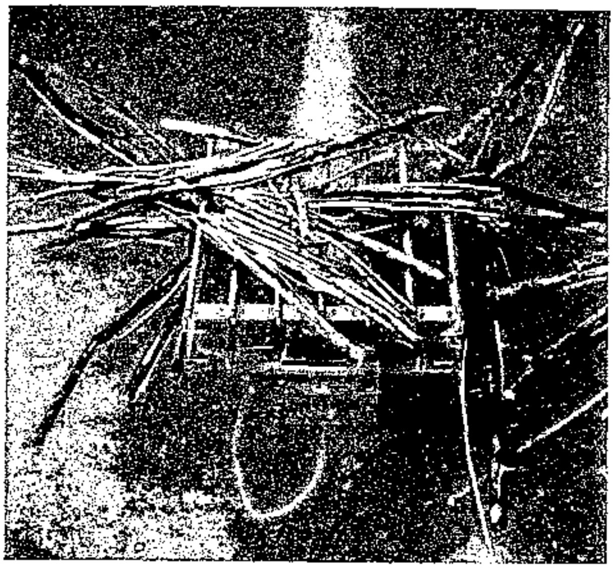


FIGURE 57.—Weir coefficients and head-discharge relations on rigid-trash tests on rack 3a.



PN—3632
FIGURE 58.—After standard rigid-trash test on model rack 3a.

PN—3633
FIGURE 59.—After standard rigid-trash test on prototype rack 3a.

weir to be practically unaffected by the trash in the flow. Figure 60 shows weir coefficients versus relative crest thickness for model and prototype, for both clear and trash flows. Rack 3b (fig. 60) was a small improvement over rack 3a (fig. 57) in the weir-flow range. In the pipe-flow range there was virtually no difference in performance between racks 3a and 3b; the crest-loss coefficients were about the same for both (table 16). Photographs of the model and prototype of rack 3b after the rigid-trash test (figs. 61 and 62) show no trash lodged in the rack sides.

Weir coefficients for rigid-trash flows in racks 3, 3a, and 3b are compared in figure 63. Rack 3a produced a significant improvement over rack 3, and rack 3b provided an additional smaller improvement. Similar improvements for pipe flow can be seen in the K_c changes in table 16. The performance of racks 3a and 3b was improved by the mesh side panels, which kept floating trash out of the structure during low flows. However, when the head-pool level rose to the top of the skirts, trash entered the structures. Of the three racks, 3, 3a, and 3b, rack 3b with the full side skirt allowed the least rigid trash to enter the structure and pass through the spillway.

Rack 4

Rack 4 (fig. 64) is similar to rack 5 (an SCS standard rack) except for a solid top plate extending a distance $D/4$ beyond the outside faces of the drop inlet. This is the minimum required overhang for the plate to exercise vortex control, as reported by Donnelly, Hebaus, and Blaisdell (footnote 2).

Rigid-trash tests were made on both a model and a prototype of rack 4. Views of these tests are shown in figures 65 and 66. A few sticks entered the open part of the prototype but appeared to have little or no effect on the hydraulic per-
coefficients to be the same for both clear water
formance of the drop inlet. Figure 67 shows weir and rigid-trash tests. The crest-loss coefficients (table 17) showed no significant increase when trash was introduced into the flow.

Plate control did not occur for this structure. The transition from weir to pipe flow occurred at an elevation about even with the underside of the plate.

Rack 5

Rack 5, having a solid plate with a $2D$ overhang, mesh sides, and horizontal rack bars in a 45-degree sloping plane, is very much like a rack tested in the $3D$-long two-way drop inlet series. The difference is in the extent of overhang, D and $1.5D$ for the two-way drop inlet series. Details of rack 5 are shown in figure 68.

Flexible- and rigid-trash tests were run on the model, and a rigid-trash test on the prototype

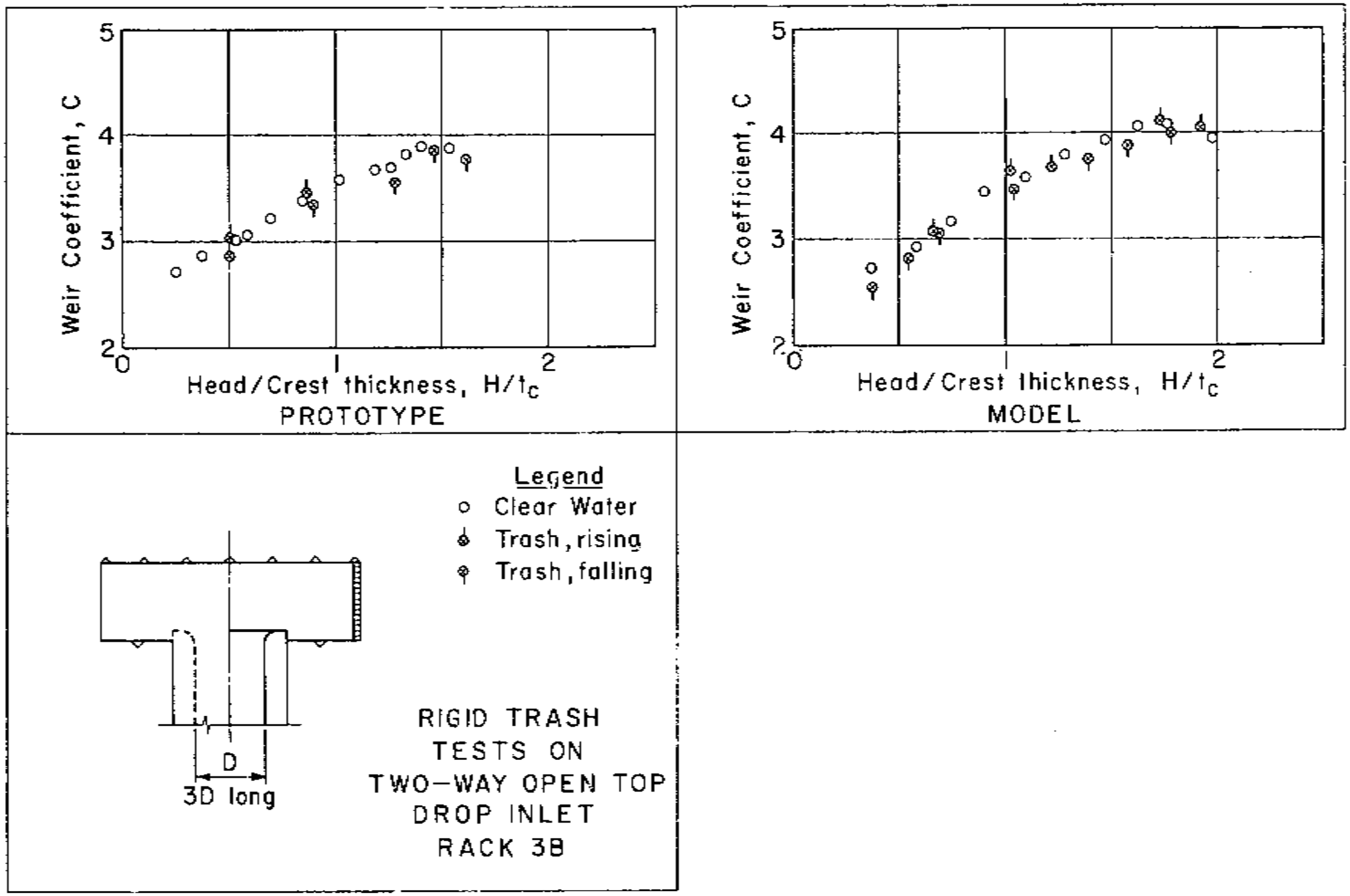
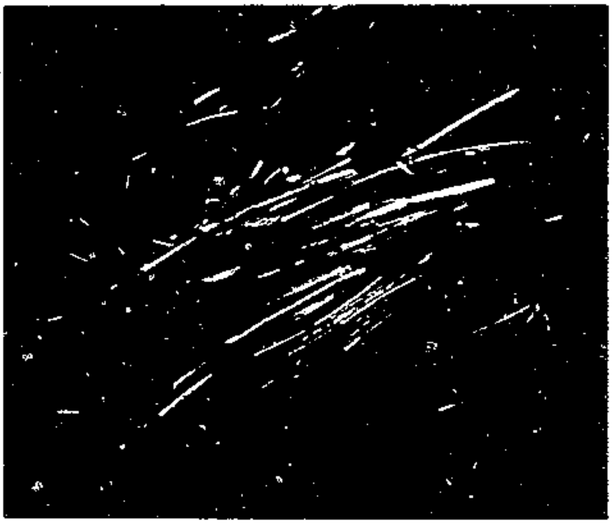
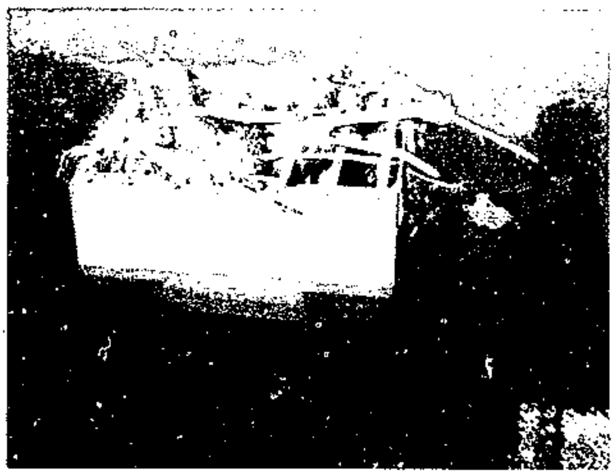


FIGURE 60.—Weir coefficients and head-discharge relations for rigid-trash tests on rack 3b.



PN—3634
FIGURE 61.—After standard rigid-trash test on model rack 3b.



PN—3635
FIGURE 62.—After standard rigid-trash test on prototype rack 3b.

only. Photographs of the model flexible-trash test and of the rigid-trash tests on model and prototype are shown in figures 69, 70, and 71. Head-discharge curves for the clear water, flexible trash, and rigid-trash tests on the model are shown in figure 72. The rigid trash had little or no effect on the capacity of the structure, but the flexible trash reduced the weir-flow capacity. Pipe-flow capacity was also reduced, but data in this range are not shown in figure 72.

The weir coefficient obtained in the flexible-trash flow test (1.95, compared with 4.2 for the

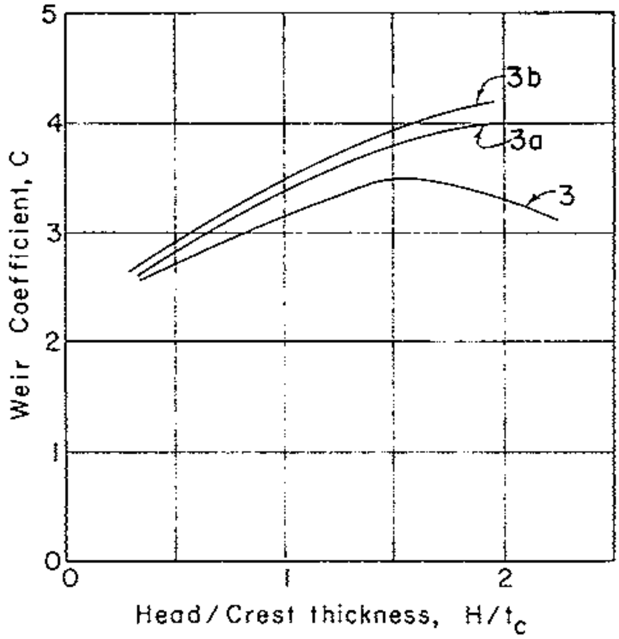


FIGURE 63.—Weir coefficients for racks 3, 3a, and 3b for rigid-trash flows.

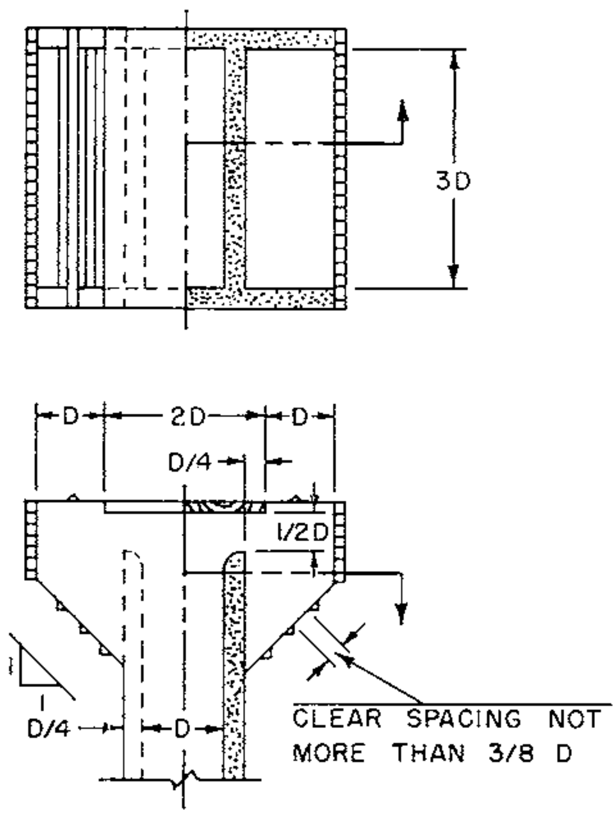


FIGURE 64.—The two-way drop inlet with minimum solid deck, laboratory modification rack 4.

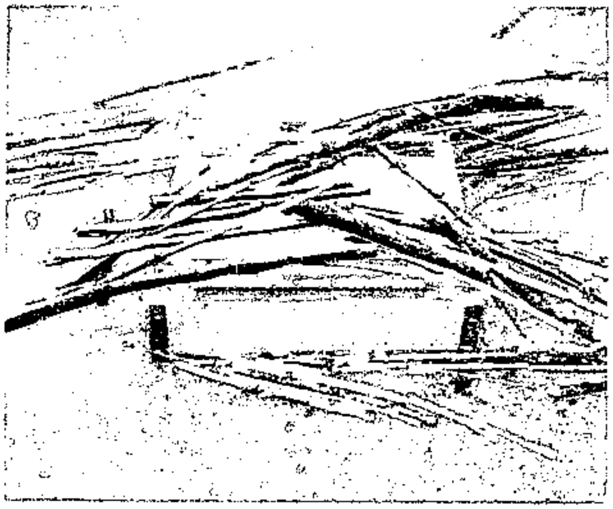


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FIGURE 65.—After standard rigid-trash test on model rack 4.

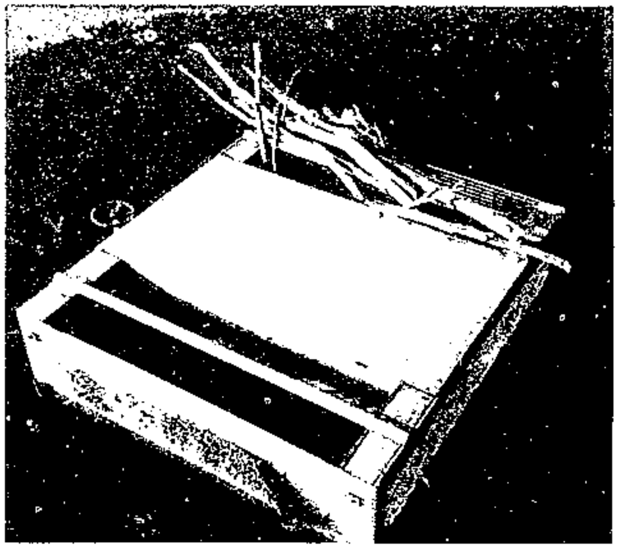

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FIGURE 66.—After standard rigid-trash test on prototype rack 4.

clear water test) indicates that the capacity reduction in the weir-flow range was 54 percent. For the rigid-trash tests the weir coefficient was unchanged from the value obtained in the clear water tests.

Rigid trash in the flow had little or no effect on the crest-loss coefficient. Flexible trash, however, increased the crest-loss coefficient over the clear water value by 150 percent. Data are given in table 18.

TABLE 17.—*Test results for two-way drop inlet, 3D-long rack 4*

Test scale	Trash load[1]	Weir coefficient, C		Crest-loss coefficient,[2] K		Trash passed (percent)
		Clear water	With Trash	Clear water	With trash	
Model	Rigid	4.10	4.05	1.28	1.29	10
Prototype	do.	3.90	3.8	1.08	1.19	7

[1] Both standard.
[2] Entrance-loss coefficients determined by weighting 6 piezometers at riser midheight.

RELATIVE PERFORMANCE OF TRASH RACKS

Performance Under Flexible-Trash Loads

Weir flow

The flexible-trash loads were intended to provide the severest test of trash-rack performance. Although the loads may appear unrealistically heavy in the photographs, no laboratory test caused a reduction in flow capacity approaching reductions observed in the field. Flow measurements on a hillside inlet in the field show that trash reduced the weir-flow capacity of the inlet to 2.5 percent of its clear water capacity. In the worst case, the standard laboratory test on the model of this structure reduced the flow to 14 percent of the clear water capacity. The coefficient values for these observations are listed in table 4.

The flexible-trash tests, while not duplicating the severity of some trash flows in the field, were consistent. Thus, at least, they furnish a valid comparison of the efficiency of various trash racks. In table 19, racks are ranked on the basis of their maintenance of clear water weir-flow capacity in standard flexible-trash tests.

Percent of clear flow capacity maintained is based on the lowest trash-flow weir coefficient

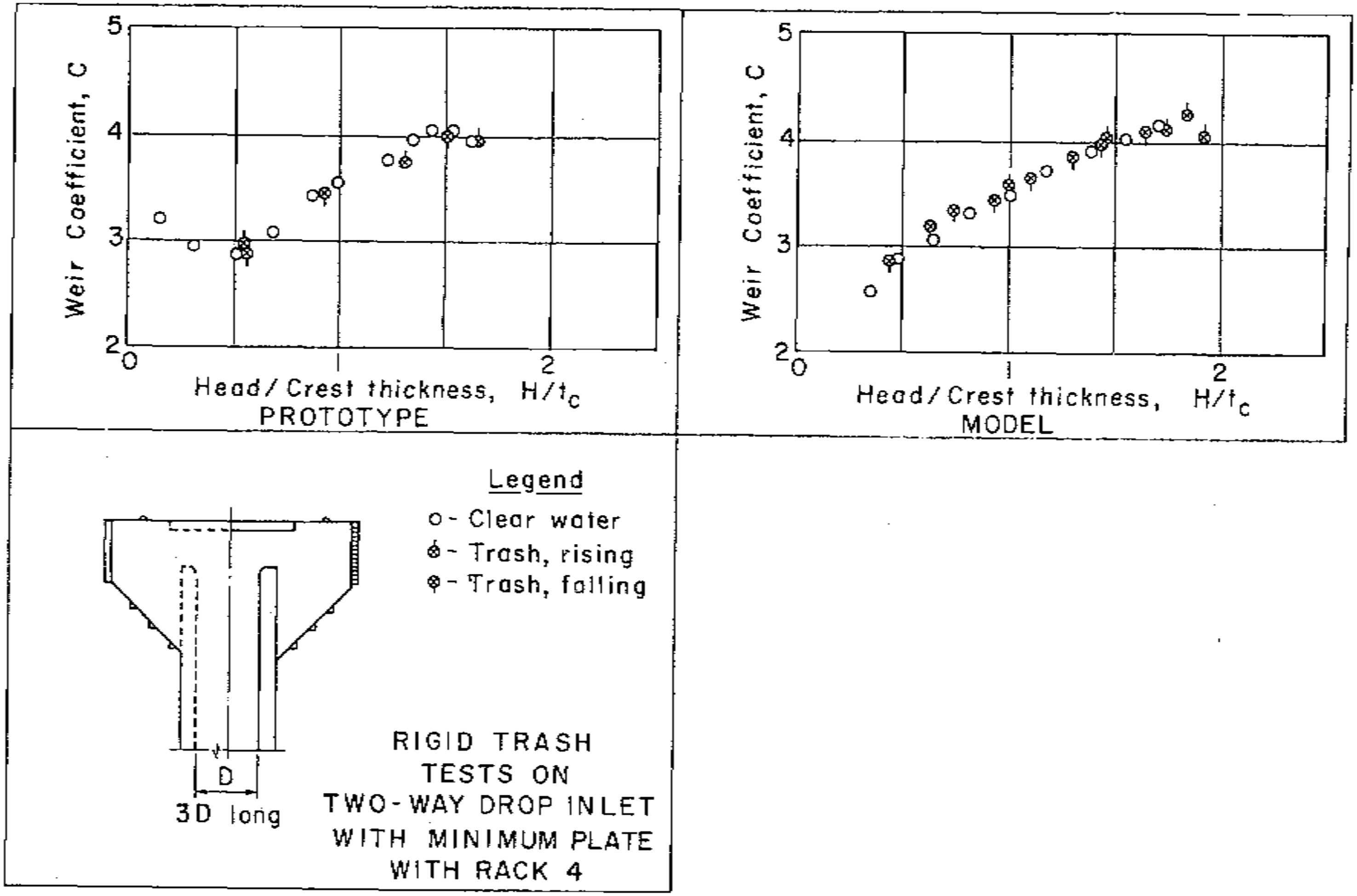


FIGURE 67.—The two-way drop inlet with minimum solid deck, laboratory modification rack 4.

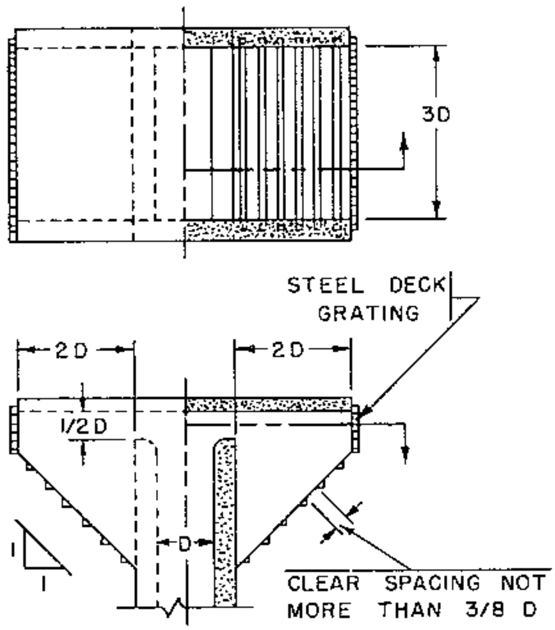


FIGURE 68.—The two-way drop inlet with full solid plate and standard trash rack 5.

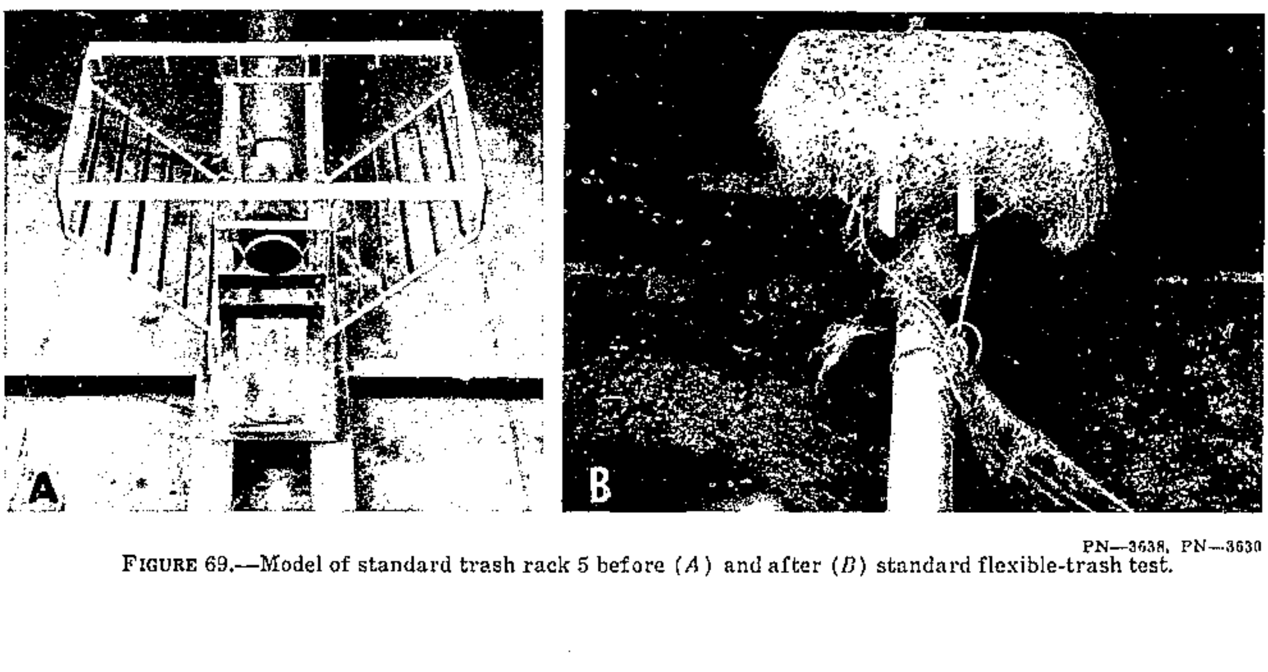
and the clear-flow weir coefficient for the corresponding head, as listed in the data tables. Since the lowest trash coefficients occurred at different heads for different racks, the comparisons made in table 19 and also in tables 20 and 21 are not for a common head, but for the worst condition, i.e., the lowest trash coefficient in each case.

Racks 1, 2, 3a, 3b, and 4 were not tested with flexible trash, and are not included in table 19. It is estimated that they would rank about as follows:

Rack 1	In last place.
Rack 2	After rack 2a.
Rack 3a	After rack 3.
Rack 3b	After rack 3a.
Rack 4	Same as two-way inlets.

An average value of flow-maintenance capabilities (38 percent) is given for the 16 two-way, $2D$-long racks tested because the differences between racks are small and the effect of changing some element of the rack, say the L_o/D ratio, is not necessarily consistent for all combinations of the rack elements. An effort was made, however, to determine the effect of each element of rack form on performance by calculating the average percent of flow maintenance for all racks having the same value for a selected rack element. Table 20 gives the results of this calculation. The first line in this table shows, for example, that the average clear water flow maintained by all racks having an L_o/D ratio of 1 (there are eight racks with this ratio) is 36 percent.

The percentage of flow maintained varied considerably within a group. For a rack with an L_o/D ratio of one, the range was from 25 percent to 55 percent. So the differences among the means reported in table 20 may not be significant. A statistical analysis of the variance within each group, in which confidence limits were



PN—3638, PN—3630

FIGURE 69.—Model of standard trash rack 5 before (A) and after (B) standard flexible-trash test.

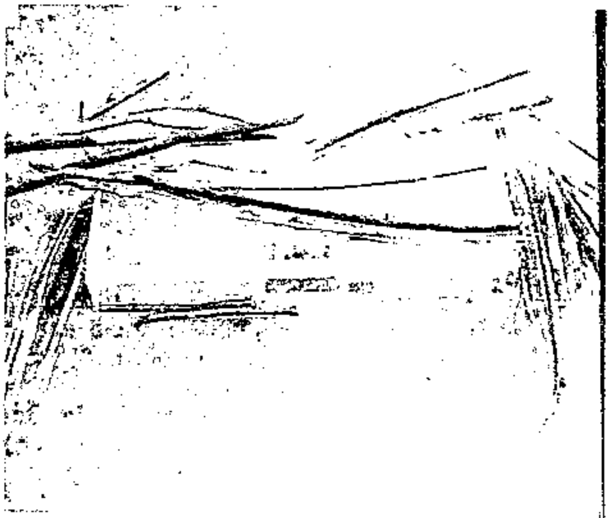


FIGURE 70.—After standard rigid-trash test on model rack 5.

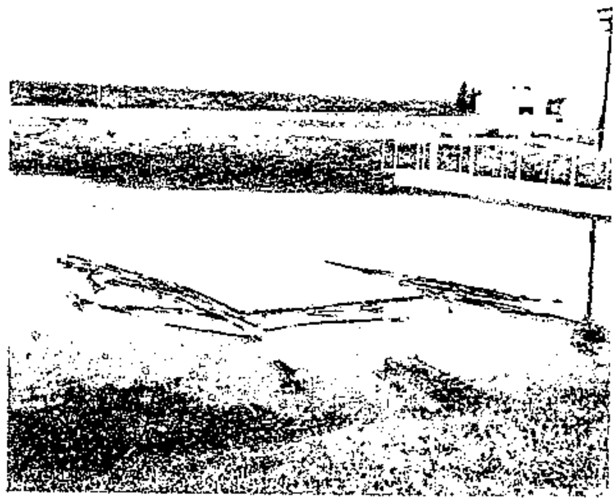


FIGURE 71.—After standard rigid-trash test on prototype rack 5.

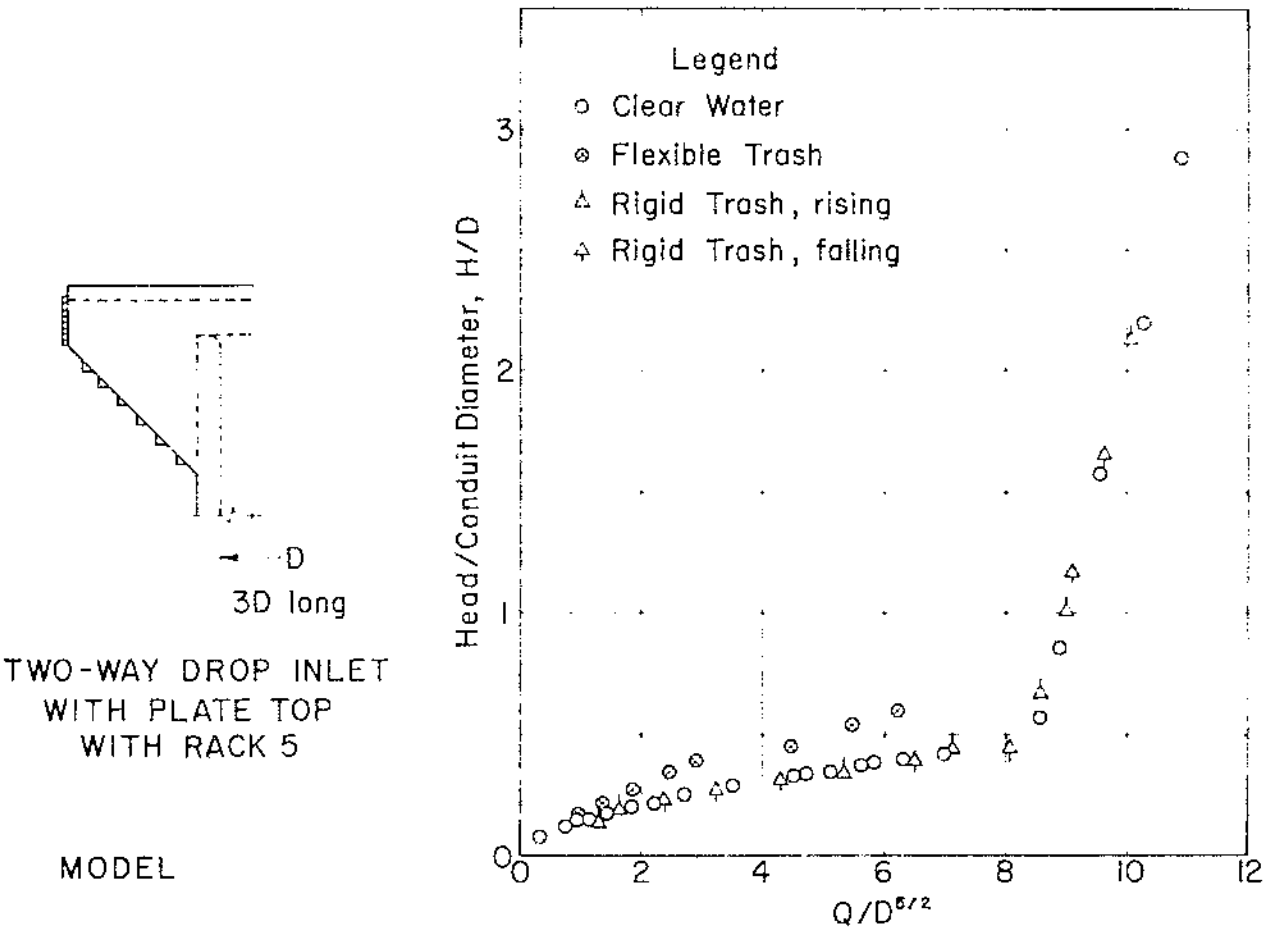


FIGURE 72.—Comparison of flexible- and rigid-trash tests on rack 5.

TABLE 18.—*Test results for two-way drop inlet, 3D-long rack 5*

Test scale	Trash load[1]	Weir coefficient, C		Crest-loss coefficient,[2] K_e		Trash passed (percent)
		Clear water	With Trash	Clear water	With trash	
Model	Flexible	4.2	1.95	1.17	2.92	1
Do.	Rigid	4.2	4.2	1.17	1.23	0
Prototype	do.	4.0	4.0	.81	.82	0

[1] All standard.
[2] Entrance- loss coefficients determined by weighting 6 piezometers at riser midheight.

established at the 90-percent level, indicated that the extent of overhang, as represented by the L_o/D ratio, did not affect the flow-maintenance capability of the rack. Neither did rack-bar spacing nor plate height have a significant effect.

TABLE 19.—*Rank of model racks by capability to maintain weir flow capacity in the standard flexible-trash test*

Rack	Coefficient data in table No.	Percent flow capacity maintained
Square, 4-way drop inlet	3	93
2-way, 3*D*, no rack bars	7	83
Rack 2a	15	68
Rack 5	18	46
Rack 3 (with center wall)	16	43
2-way, 2*D* all racks except the one without bars	6	38
2-way, 3*D*, all racks	7	36
Hillside	4	14
Rack 1 (high)	14	5

However, the racks with solid skirts performed better than similar racks with mesh sides.

A similar analysis and comparison was made of the two-way, 3*D*-long trash-rack tests. The results are given in table 21.

Percentages of the flow maintained also varied considerably for the 3*D*-long two-way drop inlet. Analysis of variance showed that some of the differences among the means reported in table 21 are not significant. There was no difference between the two overhangs, $L_o/D=1$ and $L_o/D=3/2$. However, when the percentage values for these two racks are examined together with the percentage observed for rack 5, a trend appears. Rack 5 has an overhang ratio, L_o/D, of 2, and it maintained a flow capacity of 46 percent. Thus, there is evidence of improved performance with increased overhang. The kind of skirt, solid or mesh, made no difference in rack performance. With the 2*D*-long drop inlet a difference was found. No reason for this inconsistency is apparent except that a statistical test at the 90-

TABLE 20.—*Weir flow-maintenance capability for two-way 2D-long racks, averaged for racks having a common element of rack form (from flexible-trash tests on model)*

Rack element	Percent of clear water-flow maintained
$L_o/D=1$	36
$L_o/D=3/2$	38
$Z_p/D=1/2$	43
$Z_p/D=1$	32
Skirt	42
Mesh side	32
Rack-bar spacing $4D/9$	38
Rack-bar spacing $D/3$	36

TABLE 21.—*Weir-flow-maintenance capability for two-way, 3D-long trash racks, averaged for racks having a common element of rack form (from flexible-trash tests on models)*

Rack element	Percent of clear water flow maintained
$L_o/D=1$	35
$L_o/D=3/2$	38
$Z_p/D=1/2$	41
$Z_p/D=1$	33
Skirt	35
Mesh side	38
Solid plate	33
Mesh plate	41

percent level is not very sensitive, and the 1-in-10 chance event may have occurred. Plate type made a difference, with the mesh plate giving a better performance than the solid plate. Plate height also made a difference, with the greater plate height, $Z_p/D=1$, performing better than the lesser plate height, $Z_p/D=1/2$.

The two racks which maintained weir-flow capacity best under flexible-trash loads were the square, four-way drop inlet rack and the two-way 3*D*-long rack without horizontal rack bars on the underside. The model of the first maintained 93 percent of its flow capacity. The solid side skirt and the rack-bar arrangement on the first structure are probably responsible for its fine performance. In the second case, eliminating the horizontal bars removed a trash catcher from the main flow path for weir flows, improving performance.

Table 19 also shows two racks which were poor performers, the hillside rack and the rack 1 (high). In both instances the installation was in the face of a dam, and any trash reaching the inlet had to pile up around the rack.

The two-way inlet racks were all in the intermediate-performance range. They maintained weir flow 36 to 46 percent of the clear water capacity.

Pipe flow

Changes in K_c due to trash accumulation on the rack can be determined by comparing the values for trash and clear water flows. These pairs of values are given in table 22 for all the trash racks tested. The effect of a change in K_c on the pipe-flow capacity of a closed-conduit spillway cannot be determined by examining the change in K_c alone. The crest loss is but one of several losses in the conduit. Its importance depends upon its relative value with respect to the sum of all other losses.

An expression relating change of pipe-flow discharge capacity to change in crest-loss coefficient must, therefore, include the sum of the other losses as a parameter. Such an expression is derived as explained below.

The equation for pipe flow (friction loss in drop inlet not included) is

$$Q=A_p\left(\frac{2gH}{K_c\left(\frac{A_p}{A_r}\right)^2+K_l+f\frac{l}{D}+K_o}\right)^{1/2} \qquad (6)$$

Partial differentiation of Q with respect to K_c yields

$$\delta Q=-\frac{\delta K_c A_p\left(\frac{A_p}{A_r}\right)^2(2gH)^{1/2}}{2\left[K_c\left(\frac{A_p}{A_r}\right)^2+K_l+f\frac{D}{l}+K_o\right]^{3/2}} \qquad (7)$$

Dividing both sides of the differential equation by the discharge Q results in

$$\frac{\delta Q}{Q}=-\frac{\delta K_c\left(\frac{A_p}{A_r}\right)^2}{2\left[K_c\left(\frac{A_p}{A_r}\right)^2+K_l+f\frac{l}{D}+K_o\right]} \qquad (8)$$

Factoring out K_c in the denominator and substituting

TABLE 22.—*Crest-loss coefficients for clear water and flexible-trash flows for the various trash racks*

Rack	Coefficient data in table No.	Crest-loss coefficient, K_c	
		Clear	Trash
Square, 4-way	3	0.38	0.46
Hillside	4	.23	4.49
2-way, 2*D*, $Z_p/D=1/2$	6	1.12	4.31
2-Way, 2*D*, $Z_p/D=1$	6	.35	2.36
2-way, 3*D*, mesh plate	7	.38	1.14
2-way, 3*D*, solid plate, $Z_p/D=1$	7	.45	2.62
2-way, 3*D*, solid plate, $Z_p/D=1/2$	7	1.25	4.95
Rack 1 (high)	14	.21	1.5
Rack 2	15	.30	.55
Rack 3 (with center wall)	16	.34	1.82
Rack 5	18	1.17	2.92

$$N \text{ for } \frac{K_t + f\frac{l}{D} + K_o}{K_c} \quad (9)$$

yields the desired relationship

$$\frac{\delta Q}{Q} = -\frac{\delta K_c}{K_c} \frac{\left(\frac{A_p}{A_r}\right)^2}{2\left[\left(\frac{A_p}{A_r}\right)^2 + N\right]}. \quad (10)$$

For a 3D, two-way drop inlet with a circular conduit the expression (in finite increments) reduces to

$$\frac{\Delta Q}{Q} = -\frac{\Delta K_c}{K_c} \frac{0.0342}{(0.0685+N)}. \quad (11)$$

This expression will be used to determine the relative reduction in discharge for a typical two-way, 3D, solid plate, $Z_p/D=1/2$ drop-inlet structure. Tests on this inlet showed that K_c increased from 1.25 for clear water flows to 4.95 for trash-laden flows. The effect of this change on the relative capacity of a structure will be calculated. The other loss coefficients are assumed to be

Transition-loss coefficient, K_t	$=0.6$
Pipe friction loss, $f\frac{l}{D}$	$=1.5$
Outlet loss, K_o	$=1.0$
Sum of other losses	$=3.1$

Therefore, $$N=\frac{3.1}{1.25}=2.48$$

$$\Delta K_c = (4.95-1.25) = 3.70$$

$$\frac{\Delta K_c}{K_c} = 2.96$$

$$\frac{\Delta Q}{Q} = -2.96\frac{0.0342}{(0.0685+2.48)} = -0.0397.$$

Thus, for this structure, an increase of nearly 300 percent in K_c caused a decrease of only about 4 percent in discharge capacity in the pipe-flow range.

Since the effect of an increased crest-loss coefficient on discharge is generally small, the form of the rack does not appear too critical insofar as loss of capacity is concerned. It might seem that the rack with the lowest crest-loss coefficient after the trash test would be the best one, but it is not possible to select rack form from this value alone. It may be necessary, for vortex or reservoir-level fluctuation, to set a solid plate at a height of $Z_p/D=1/2$ above the crest. Although the crest-loss coefficient for this setting is on the order of three times the coefficient for a plate height of $Z_p/D=1$, it must be used. It is in order, then, to compare the performance of racks with like plate height. Rack 5 has the smallest increase in crest-loss coefficient for all racks with a solid plate $Z_p/D=1/2$ above the crest (table 23).

Performance Under Rigid-Trash Loads

The Soil Conservation Service standard designs and the laboratory modifications to them were all tested with rigid trash to both model and prototype scales, but not all were tested with flexible trash, so performance of these racks was compared on the basis of the rigid-trash tests. Separate evaluations were made for weir and pipe flows.

Weir flow

Rigid trash alone does not provide a severe test of the performance of a trash rack. However, rigid trash lodged in a rack can intercept more flexible trash than the rack alone, so the rigid-trash test results are an indicator of potential trouble from flexible trash.

Table 23 lists the discharge capacity changes in the weir-flow range due to rigid trash accumulation on the racks.

TABLE 23.—*Rank of model and prototype racks by capability to maintain weir-flow capacity in a standard rigid-trash test*

Rack	Test scale	Coefficient data in table No.	Percent of clear water flow maintained
5	Model	18	100
5	Prototype	18	100
4	Model	17	99
4	Prototype	17	97
3b	Model	16	98
3b	Prototype	16	97
2a	Model	15	99
2a	Prototype	15	94
3a	Model	16	94
3a	Prototype	16	96
3	Model	16	83
3	Prototype	16	90
1	Model	14	83
1	Prototype	14	87
2	Model	15	75
2	Prototype	15	84

The weir-flow capacity of trash rack 5 was unaffected by the presence of rigid trash in the flow. In this respect the rack showed the best performance of any tested. Racks 4, 3b, and 2a performed nearly as well. All the best performing racks prevented sticks from entering the drop inlet.

Pipe flow

The performance of a trash rack under rigid-trash loading in the pipe-flow range was evaluated by examining the crest-loss coefficients for clear and rigid-trash flows. The coefficients for the racks subjected to rigid-trash tests are given in table 24.

Racks 4 and 5 showed only a slight increase in crest-loss coefficient in the rigid-trash tests. The largest increase in K_r of these two racks was to the prototype of rack 4, and it can be attributed to the sticks which entered the top openings in the rack. (See figure 66.) No reason for the small increase in K_r for the model of rack 5 is evident, since no trash passed through it and none was observed to lodge in it.

TABLE 24.—*Crest-loss coefficients for model and prototype racks in clear and rigid-trash flow*

Rack	Test scale	Coefficients in table No.	Crest-loss coefficient, K_r Clear	Crest-loss coefficient, K_r Trash
1	Model	14	0.30	2.2
1	Prototype	14	.19	.60
2	Model	15	.30	1.81
2	Prototype	15	.28	.76
2a	Model	15	.30	.39
3	do	16	.34	1.3
3	Prototype	16	.31	1.1
3a	Model	16	.34	.47
3a	Prototype	16	.31	.57
3b	Model	16	.34	.46
3b	Prototype	16	.31	.50
4	Model	17	1.28	1.29
4	Prototype	17	1.08	1.19
5	Model	18	1.17	1.23
5	Prototype	18	.81	.82

MODEL-PROTOTYPE SIMILARITY

The pairs of photographs 45–46, 47–48, and 54–55 show the striking similarity of the rigid-trash accumulations on the model and the prototype racks. It is not surprising to find the good agreement between the weir coefficients for the model and the prototype. This agreement is shown graphically in figures 49, 50, 51, 56, and 57, and in numerical form in tables 14 to 18 inclusive. Table 23 also shows how close the model and the prototype were in maintenance of clear water weir flow.

Model and prototype performance for pipe flow are compared in table 24, where the crest-loss coefficients are listed for both clear and rigid-trash tests. Clear water coefficients are generally very close for model and prototype. For the trash tests the agreement is not always as good, with the prototype coefficient generally being the lower one of the pair. One reason for this is the wind over the prototype reservoir, which sometimes prevented part of the rigid trash from reaching the test structure. Over the model there is no wind, and the trash members move toward the test structure without interference.

Flexible trash model-prototype comparisons are possible for only two structures, the four-way drop inlet and the three-way drop inlet with trash rack 2a. However, the effect of suspended sediment is present in the model data, and the comparisons are not as convincing as those of the rigid-trash tests.

Weir coefficients in figure 13 for the first prototype trash test on the four-way drop inlet correspond most nearly to those in figure 17 (sediment in flow) for model test 59, which had a heavy sediment load in the water. Head-discharge data for similar model and prototype tests are plotted in figure 73 for comparison. In model test, 840 grams of trash were fed. This amount of trash, scaled to prototype size by weight (using the cube of the length ratio) would be equivalent to 945 pounds. The estimated weight of the eight pickup truckloads of loose hay used in the prototype test was 1,500 pounds. The additional amount of material fed to the prototype may have compensated to some degree for the effect of suspended sediment in the model test and the trash that did not reach the prototype inlet.

In the three-way drop inlet prototype with trash rack 2a, one large truckload of grass was fed. The estimated weight of this material was

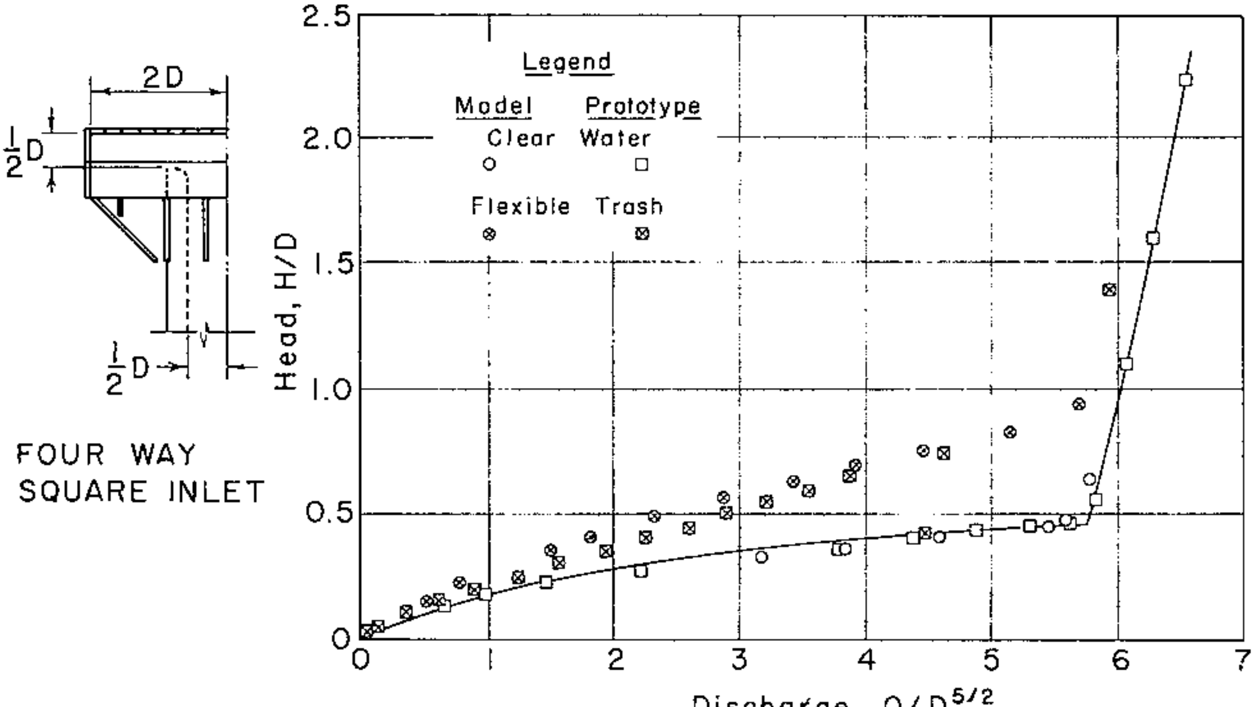


FIGURE 73.—Comparison of head-discharge relationships for clear water and flexible-trash tests on model and prototype of the four-way square inlet.

1,150 pounds. The 1,000 grams of material used in the standard flexible model test are equivalent to about 1,130 pounds in the prototype test. The similarity between the model and prototype data in figure 51 is excellent; however, the effect of suspended sediment on model performance clouds the comparison.

Close similarity between model and prototype performance is found in the rigid-trash tests on trash rack 5. Figure 74 shows the weir coefficients for the model and prototype. For both flows the model and the prototype have similar coefficient values. The trash did not have much effect on the coefficient, probably because of the small accumulations around the rack (figs. 70 and 71).

Prototype clear water values of K_c for trash racks 4 and 5 are less than those measured in the model, as indicated in tables 17 and 18. This may be due to differences in relative crest thickness. Hebaus (cited in footnote 4) has shown that in covered two-way drop inlets, K_c decreases with increasing values of t_c/D. In the models, t_c/D was 0.250, but in the prototypes, it was 0.333.

SIMILARITY OF LABORATORY TESTS TO FIELD CONDITIONS

The standard flexible-trash test was intended to be severe and may not seem to be representative of field conditions, since no substantial amounts of loose hay and grass were found at Oklahoma flood-detention reservoir sites. However, no flexible-trash accumulation on a model resulted in as great a reduction in the weir coefficient as the reduction observed on the field-installed hillside inlet with a trash-choked rack. So the tests may not have been too severe after all. The standard rigid-trash test was also intended to be severe, yet the accumulation of sticks on and around the racks after a rigid-trash test did not appear excessive and provoked the same doubts about their realism as the flexible-trash tests.

Realism combined with quantitative results from model tests would be highly desirable. Efforts were made to find materials and procedures which would give the same results for

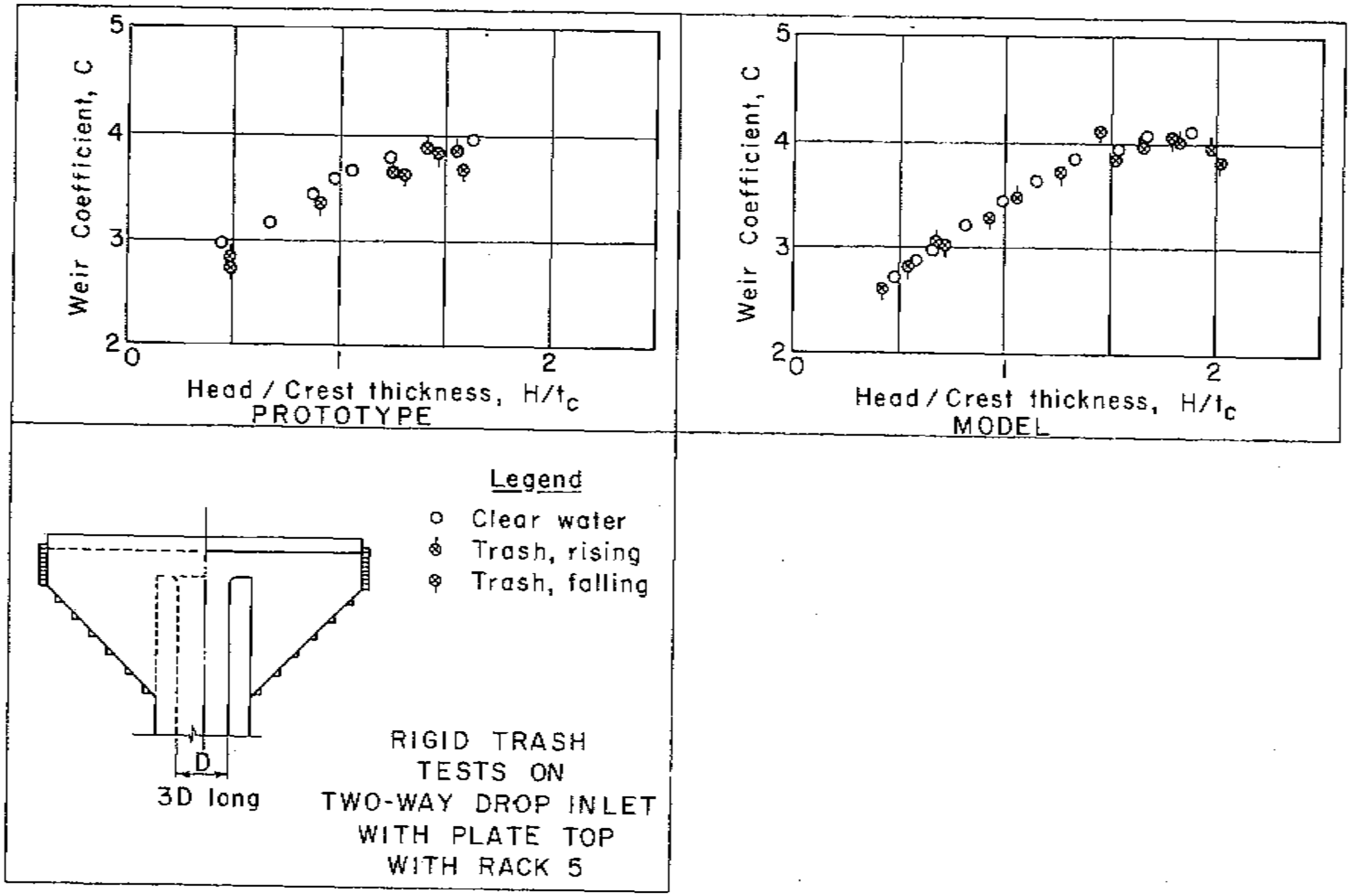


FIGURE 74.—Weir coefficients for two-way drop inlet 3D long with overhang of 2D and with a solid plate rack 5, for rigid-trash tests on model and prototype structures.

model and prototype, and some success was gained with controlled trash. That is, when all trash was of one kind and was fed in the same relative amounts to model and prototype, like results were obtained as to duplicating field conditions. Field trash will be whatever floats in with the flow and every load will be unique, so there is no hope of predicting the consequences of every trash load by a model test. The only practical approach is to use standardized trash loads so that the relative effectiveness of the different racks can be compared. But more than comparative results were obtained in these tests: an estimate of the order of magnitude of flow-capacity loss as a result of trash accumulation on the various racks can be made from the laboratory test data.

COMPARISON OF FLEXIBLE- AND RIGID-TRASH FLOWS

Head-discharge curves are presented in figures 75 and 76, comparing curves for clear water, flexible trash, and rigid trash for two racks. Flexible trash in the flow greatly reduces their discharge capacity in the weir-flow range. Rigid trash has practically no effect. Packing of the flexible trash, which obstructs flow, is responsible for the reduction capacity. Even an accumulation of rigid trash is much more open, and its effect on flow capacity is very small.

TRASH-RACK MAINTENANCE

Removal of trash from a rack after a trash-laden flow is a major concern. Laboratory observations concerning the removal of trash from the various racks may, therefore, be useful.

In almost all of the structures tested with flexible trash, with the exception of the hillside inlet and the three-way square drop inlet with trash rack 1 in the dam face, trash that lodged on the

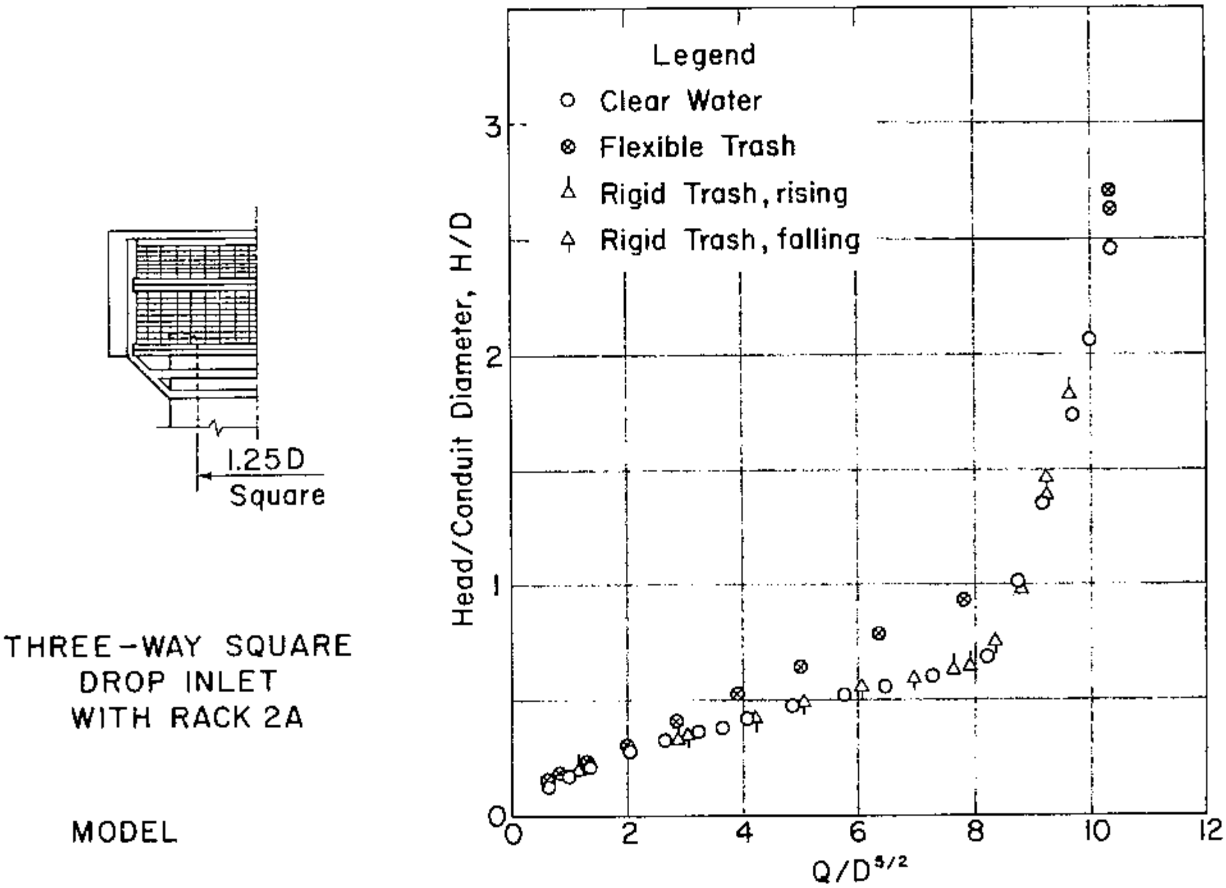


FIGURE 75.—Comparison of flexible- and rigid-trash tests on rack 2.

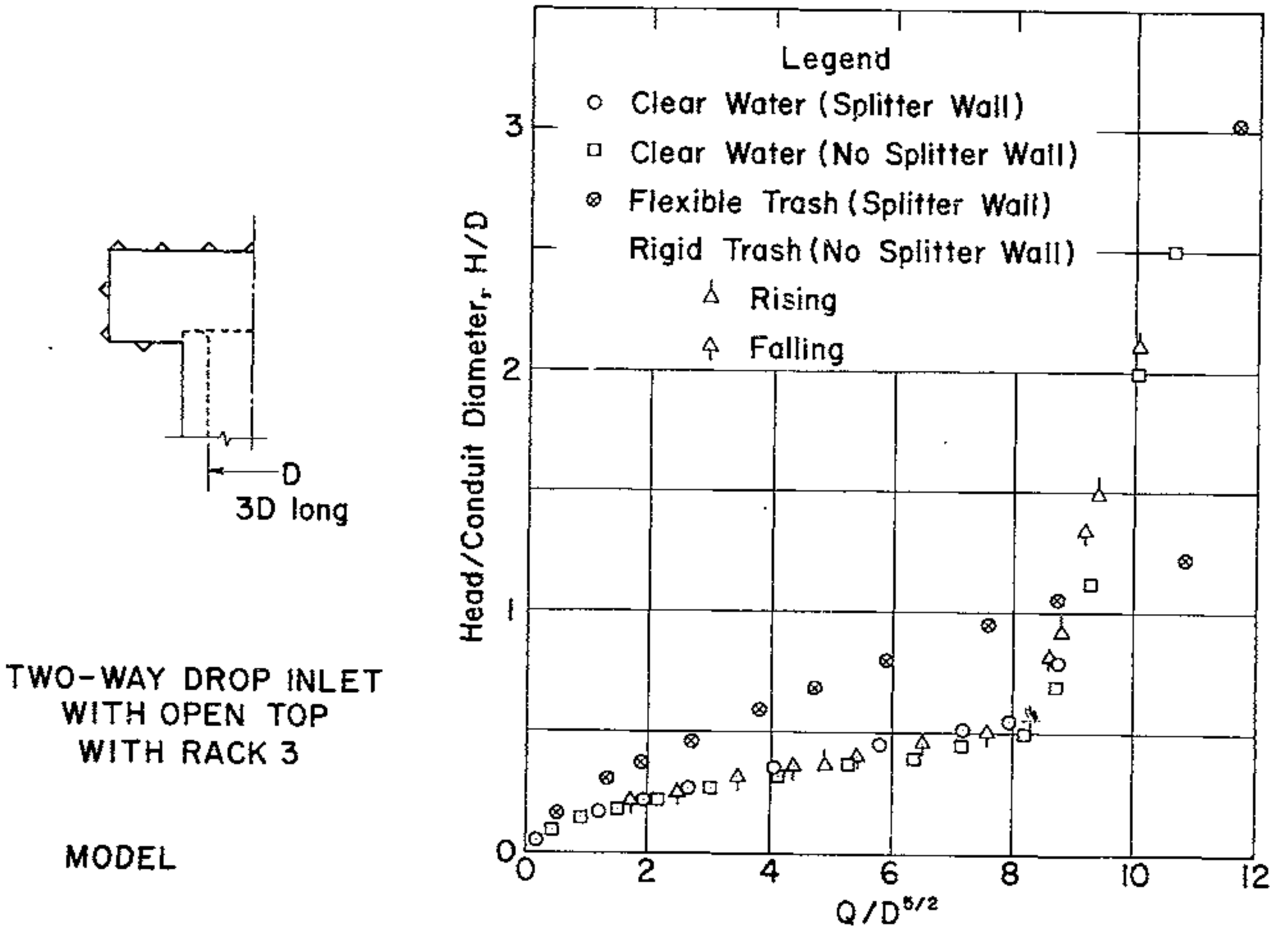


FIGURE 76.—Comparison of flexible- and rigid-trash tests on rack 3.

bars on the underside of the racks fell off when the head pool was lowered. This can be seen in figures 14, 15, 35, and 69. The underside of these racks slope upward and away from the drop inlet, so that flexible trash does not pack tightly against the bars and tends to fall away readily.

Rigid trash, on the other hand, lodged inside the rack and in the drop inlet of the open-type racks (figs. 39, 40, 45–48, 54, 55, 58, and 59) and was sometimes difficult to remove. There was no difficulty in removing the logs and sticks lodged in the upper part of rack 4 (fig. 66).

Mesh plates or open tops attracted considerable trash to the top of the rack. Figure 36b shows the large "haystack" atop the open mesh plate on a two-way, 3*D*-long drop inlet following a flexible-trash test. A similar structure, having a solid plate instead of open mesh, collected much less trash on top for the same test (fig. 35b). Other open-top racks with flexible-trash accumulations on top are shown in figures 42b and 53b. Rigid trash also accumulated on open top structures, as shown in figures 61, 62, 65, and 66. This trash should be removed because it reduces the capacity of the structure below design value, and also, can constitute a fire hazard. Solid-plate racks should present less of a maintenance problem in this respect than the mesh-plate or open-top racks.

From the standpoint of maintenance, rack 5 is probably the most trouble-free. No rigid trash entered this structure or lodged on the rack in either the model or the prototype. Flexible trash fell off the bars in the model when the head pool was lowered.

SIGNIFICANT FINDINGS

Techniques were developed for making model tests of trash racks for drop inlets on closed conduit spillways. Good agreement between results on small-scale models in laboratory flumes and on large-scale structures in an outdoor basin, attributable to the use of controlled trash loads, make it possible to estimate the relative performance of different rack forms from the standardized trash tests.

The two types of trash studied, flexible and rigid, behave differently in the flow. Rigid trash floats on the water surface and can be kept out of the trash rack by a skirt or a mesh side panel. Flexible trash, on the other hand, tends to become waterlogged and to submerge slowly. When at or near the density of water, this trash is carried along by the flow stream, which may be entering the rack beneath the water surface, and pieces may catch on and wrap around rack bars. Considerable trash can build up on the rack-trash that, if not intercepted, would pass harmlessly through the structure.

Racks with underside bars arranged in an upward and outward pattern from the drop inlet tend to be self-cleaning. Much of the trash on such bars drops off when the water surface is lowered below the rack. The water can be lowered this much when a low-stage orifice is used or where, with single-stage outlet structures, evaporation and seepage losses exceed runoff and direct rainfall gains for relatively long periods of time—the usual situation in subhumid or dry areas.

Trash racks being used in 1969 were tested in the laboratory, using both small-scale and large-scale test structures. Flexible- and rigid-trash tests were performed. Of these racks, trash rack 5 performed the best. Its solid plate and mesh sides prevented the entry of rigid rash into the rack. Its ample overhang, $2D$, created a large area which was not readily plugged by standard flexible trash. However, this rack must be limited to use in open water because the greater part of the flow approaches this structure through the part of the rack below the crest of the inlet.

The two poorest performers were the hillside inlet rack and rack 1 installed on a three-way square drop inlet on the face of a dam. Their open construction allows rigid trash to enter and lodge, and since the crest is level with the berm, large amounts of flexible trash accumulate on on and around the rack.

Model-scale racks for two-way drop inlets in open water were systematically investigated, using flexible trash. For the $2D$-long structures the variables investigated were length of overhang, height of plate, skirt or mesh side, and rack-bar spacing. Changing the overhang from D to $3D/2$ had no effect on weir capacity. Neither did changing rack bar spacing from $4D/9$ to $D/3$.

Reducing plate height from D to $D/2$ reduced the weir coefficient for clear water flows. But when trash was introduced into the flow, the racks with a plate height of $D/2$ showed a relatively smaller reduction in weir coefficients than the racks with a plate height of D. Racks with skirts maintained flow capacity better than racks with mesh sides. For the $3D$-long structures, the results were much the same for all rack components except for the skirt versus mesh-side comparison. For the longer drop inlet, the mesh side performed better. No reason for this reversal has been found. Statistical tests showed the differences (at the 90-percent confidence level) to be real for both the $2D$- and $3D$-long drop inlets. Different top plates were used for the $3D$-long structure tests. The mesh top maintained a higher percentage of weir flow capacity than the solid plate.

RECOMMENDATIONS

For two-way drop inlets in open water, a rack with a solid plate and a solid skirt extending below the inlet crest level is recommended. Ventilation must be provided between the plate and skirt so that siphoning will not occur, unless such action is desired. If the vent is made by leaving an open space between the underside of the plate and the top of the skirt, this open space should be covered with mesh to prevent the entry of sticks. Rack bars should be placed in a plane sloping downward from the bottom edge of the skirt to the side of the drop inlet, to prevent rigid trash, floating alongside the drop inlet at low water, from rising with the water and entering the space between the skirt and the drop inlet side.

The rack on the four-way square drop inlet performed well. However, if a rack of this type is used, a mesh-covered ventilation space between the skirt and the plate should be provided.

The racks investigated in this study are generally best suited for open-water installatons. For installations in hillside locations or berms of dams, or for sediment-filled reservoirs, a different style of rack, as yet undeveloped, is needed.

APPENDIX.—THE MOVEMENT OF TRASH IN A RESERVOIR

Once trash enters a reservoir, whether or not it will reach the outflow structure will depend upon the magnitude and direction of the water and wind currents acting on the trash.

The relative effects of wind and water currents on floating trash can be estimated by calculating the forces exerted by the two currents on a log of diameter d, oriented perpendicular to the wind and floating half-submerged. Let the wind velocity be V and assume a uniform profile. For simplicity, assume that the wind does not affect the water movement below the surface, so that the current flow can be described by a flat profile of velocity v opposite to the wind direction. If the log is prevented from rotating, the current velocity necessary to hold the log stationary against any given wind velocity can be calculated.

The velocities V and v create drag forces similar to those resulting from flow around a two-dimensional cylinder. The drag force F of the air is

$$F = C_{Da}\frac{A}{2}\rho_a\frac{V^2}{2} \qquad \text{(A–1)}$$

and the drag force f of the water is

$$f = C_{Dw}\frac{A}{2}\rho_w\frac{v^2}{2}, \qquad \text{(A–2)}$$

where C_D is the drag coefficient for a two-dimensional cylinder, A is the cross-sectional area of the log, and ρ_a and ρ_w are the densities of air and water, respectively.

For equilibrium F should equal f, or

$$\frac{F}{f} = 1 = \frac{C_{Da}\rho_a V^2}{C_{Dw}\rho_w v^2}. \qquad \text{(A–3)}$$

At 60°F $\rho_a = 0.00237$ slug/ft³ and $\rho_w = 1.94$ slug/ft³ so that

$$\frac{V}{v} = \sqrt{\frac{1.94}{0.00237}\cdot\frac{C_{Dw}}{C_{Da}}} = 28.6\sqrt{\frac{C_{Dw}}{C_{Da}}}. \qquad \text{(A–4)}$$

The Reynolds number R for the air flow and the water flow are

$$R_a = \frac{Vd}{\nu_a} \qquad \text{(A–5)}$$

and

$$R_w = \frac{vd}{\nu_w}, \qquad \text{(A–6)}$$

where ν is the kinematic viscosity, and at 60°F,

$$\nu_a = 1.6\times10^{-4}\ \text{ft}^2/\text{s and } \nu_w = 1.2\times10^{-5}\ \text{ft}^2/\text{s}.$$

From equations A–5 and A–6

$$\frac{V}{v} = \frac{16}{1.2}\cdot\frac{R_a}{R_w} = 13.3\frac{R_a}{R_w}. \qquad \text{(A–7)}$$

Since equations A–4 and A–7 express the same ratio,

$$\frac{R_a}{R_w} = 2.15\sqrt{\frac{C_{Dw}}{C_{Da}}}. \qquad \text{(A–8)}$$

The velocity ratio must therefore satisfy compatible values of the drag coefficient C_D and the Reynolds number R. The current velocity can then be calculated for any given wind velocity and log diameter.

Current velocities were calculated for assumed wind velocities of 10, 5, and 2 miles per hour acting perpendicular to the longitudinal axis of a 3-inch-diameter log. The results are listed in table A–1. Values of the drag coefficient C_D and the Reynolds number R were obtained from Rouse's figure 126.[1]

Table A–1 shows that with only a very slight breeze (2 miles per hour) an oppositely directed water current of at least 0.1 foot per second would be necessary to hold the 3-inch log steady in the presence of the wind. Currents of this magnitude probably do not exist in most reservoirs, except near the inlet. Thus, in most cases,

[1] Rouse, Hunter. 1959. Elementary mechanics of fluids. John Wiley & Sons, Inc., New York.

TABLE A–1.—*Calculations of water velocities to hold 3-inch-diameter log stationary against corresponding wind velocities*

Wind velocity, V: Miles per hour	Wind velocity, V: Feet per second	Reynolds number of air, R_a	Drag coefficient of air, C_{Da}	Reynolds number of water, R_w	Drag coefficient of water, C_{Dw}	$\frac{C_{Dw}}{C_{Da}}$	$2.15\left(\frac{C_{Dw}}{C_{Da}}\right)^{1/2}$		$\frac{R_a}{R_w}$	Water velocity[1] (feet per second)
[2]10	14.65	2.29×10^4	1.25	1.0×10^4	1.0	0.80	1.92	$\neq$	22.9	...
10	14.65	2.29×10^4	1.25	1.0×10^4	1.1	.88	2.02	$\neq$	2.29	...
10	14.65	2.29×10^4	1.25	1.1×10^4	1.2	.96	2.11	$\approx$	2.08	0.53
[3]5	7.33	1.14×10^4	1.20	6.0×10^3	.97	.809	1.93	$\approx$	1.90	.29
[3]2	2.93	4.58×10^3	.96	2.1×10^3	.97	1.01	2.16	$\approx$	2.18	.10

[1] $v=\frac{V}{13.3\,(R_a/R_w)}$.

[2] Entries for 10 miles per hour are results of 3 trials.

[3] Entries for 5 and 2 miles per hour are final approximations.

floating logs and sticks can be easily moved around a reservoir by very slight winds.

The assumptions used in this brief analysis oversimplify actual conditions. Considering the drag of the wind on the water surface, currents even greater than those indicated would be necessary to hold the log in equilibrium with the wind forces.

The relative orientation of the log, the wind, and the current direction was chosen for ease of analysis. With other orientations, force components would have to be considered. If the log were oriented parallel to the wind and current directions, approximately the same result would be obtained. For this case, assuming the ends of the log are blunt and of the same size, the drag coefficients in water and air are equal since the Reynolds number is greater than 1,000 in either case (Rouse, p. 249). This gives a velocity ratio V/v of 28.6 from equation A–4. From table A–1, the average value of V/v is approximately 27. By comparing values of V/v for the extreme log orientations and considering the assumptions made, it can be concluded that V/v is approximately 30 for all log orientations.

Considering the significant influence of the wind, the location of the drop inlet in the reservoir may have an appreciable effect on the magnitude of the trash problem. Drop inlets located in the corner of the reservoir, as many of the older hillside type were, may have serious trash problems if the wind direction is favorable for trash accumulation at the structure. Most newer structures do not have this problem, because they are placed nearer the center of the dam.

Forces due to circulation can arise in asymmetrical reservoirs, or even in symmetrical reservoirs where the inflow channel is not directly alined with the drop inlet. These forces probably have their greatest effect on submerged trash with a density near that of water. The flow of this material will not be affected by wind if it is deeply submerged. It can, therefore, be easily moved along with undercurrents. Even thermal or density currents could cause its movement.

It would be difficult, if not impossible, to evaluate the effects of circulation forces on trash in a reservoir. In large reservoirs they would probably be negligible, but they can exist, and the geometry of the reservoir and the approaching channel should be considered in locating the drop inlet to avoid trash accumulations resulting from circulation.

In general, wind and circulation forces act over the entire reservoir. When the flow very near the drop inlet is considered, other forces become important. Weir flow creates a water-surface drawdown near crest of the structure. In this region the flow has appreciable velocity, and will carry any floating or submerged trash toward the structure.

Ruff,[2] in reporting on tests of model trash

[2] Ruff, Paul F. 1958. Model studies of spillways. Univ. Calif. Inst. Eng. Res., Service to Industry Series No. 6079.

racks for drop inlets, points out that for free surface weir flow penetrating an open rack, floating sticks were attracted to the inlet almost immediately after flow had begun. On the other hand, a solid skirt around the structure extending below crest level and above the weir-flow water surface was very effective in keeping floating sticks almost at a standstill. Figure A–1 illustrates why this should be so. The open trash rack allows the water surface to slope toward the inlet, but the solid skirt interrupts the free surface flow and causes a stagnation point. Upstream of the solid skirt the free surface has very little velocity. Thus, floating trash can be prevented from packing tightly against the trash rack by the use of a solid side skirt.

The preceding qualitative description of trash movement is intended to bring out two points. (1) Several forces can move trash in a reservoir; the most significant of these is wind. The forces can combine in many ways, contributing both positively and negatively to the trash problem. (2) It can be seen that trash motion is virtually unpredictable. Therefore, there appears to be no valid guide for predicting that a given spillway need or need not be equipped with an entrance trash rack. However, the consequences of failure of a floodwater-retarding structure by plugging of the principal spillway can be so severe that a trash rack is essential to guard against even a remote possibility of such a failure. Moreover, the factor of human safety demands some protective device at spillway entrances.

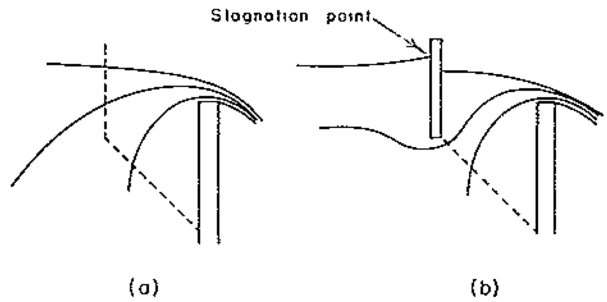


FIGURE A–1.—Water surface shapes for weir flow without (*A*) and with (*B*) a solid skirt.

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