Progress Report No. 1

# HYDRAULIC MODEL STUDIES RELATING TO THE REDESIGN OF THE SPILLWAY AND POWERHOUSE FOR THE DAVIS DAM

Hydraulic Laboratory Report Hyd. 232

Bureau of Reclamation
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Branch of Design and Construction
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Denver, Colorado
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Laboratory Report No. 232
Hydraulic Laboratory
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Reviewed by: J. N. Bradley and
J. E. Warnock

Subject: Hydraulic model studies relating to the redesign of the spillway and powerhouse of Davis Dam.

## INTRODUCTION

Three hydraulic models of Davis Dam were tested in 1942-1943, and the results are reported in memorandum to Chief Designing Engineer, Hydraulic Laboratory Report HYD 123, entitled, "Hydraulic Model Studies Relating to the Design of the Davis Dam." Two of these models were of particular significance in the present investigation. The recommended spillway bucket, referred to in this report as the specification bucket, was evolved from studies on 1:100, and 1:48 scale models. The 1:100 scale model included the spillway, powerhouse, and sections of the river channel both upstream and downstream from the structures. The 1:48 model was a sectional model used to determine the characteristics of various buckets and aprons with special emphasis on erosion below the structure.

After extensive tests on both models, the stilling structure recommended for construction consisted of a low bucket which served as a roller bucket for low discharges and as a trajectory bucket for the higher discharges.

This bucket is shown schematically in this report as Test 1. Cost and tailwater conditions prevented the use of a hydraulic jump apron while much additional excavation would have been necessary to make use of a roller bucket for the entire range of flow conditions.

Due to differences in foundation conditions at the damsite, revealed during the early stages of construction, the present investigation was

undertaken. Extensive tests made on a 1:72 model indicated essentially the same results as obtained in the earlier tests. In addition, however, the dangerous effects of an eddy in the dead water area downstream from the powerhouse and adjacent to the spillway were recognized, and attempts made to reduce its harmful effects. The present tests were made with no flow through the powerhouse which results, probably, in a worse eddy condition than with flow through the turbines. In the earlier tests, the powerhouse was in operation during all spillway tests.

This report was requested by Assistant Chief Engineer Nalder for use by the consulting board and others responsible for the design of Davis Dam. The material presented gives the results of tests made between April 1 and July 25, 1947.

## SUMMARY

The specification bucket, recommended as a result of the 1942-1943 tests was installed in the 1:72 scale model. Erosion was not excessive below the bucket lip, but with no flow through the powerhouse, the eddy in the dead water area on the right side extended into the powerhouse tailrace causing excessive erosion along the downstream face of the powerhouse, and at the end of the right spillway training wall.

To reduce the harmful effects of the eddy, various schemes were tried. A relatively long hydraulic jump apron was tested and found to operate satisfactorily for present tailwater conditions. For high discharges with the ultimate tailwater elevation, however, the jump swept out of the apron and operation was then similar to the specification bucket.

Present tailwater is the elevation of tailwater expected to obtain immediately after the structure is placed in operation. Ultimate tailwater will obtain after degradation of the riverbed has occurred. Thus, ultimate tailwater is about 20 feet lower than present tailwater. Both tailwater operating curves are shown in Test 2.

The specification bucket was reinstalled in the model with the lip at elevation 490, and the existing rock between the spillway and the

powerhouse reproduced in nonerodible concrete. Tests then showed that the erosion at the bucket lip, and in the powerhouse tailrace was reduced since the eddy was reduced in size and intensity. For ultimate tailwater conditions, however, the eddy persisted and tended to undermine the rock projection.

The specification bucket was then raised in steps until the lip was at elevation 515.0. At this elevation, the jet leaving the bucket was above the tailwater for all discharges and tailwater elevations and the water was thrown downstream the maximum distance possible. The resulting erosion was deep near the bucket lip, and the destructive action of the eddy was not noticeably reduced. The addition to the model of a cofferdam structure located near the line of the right training-wall, part of a cofferdam necessary for prototype construction, failed to decrease the effects of the eddy.

A deep bucket was next tried in the hope that the velocities at the end of the apron would be reduced sufficiently to also decrease the eddy velocity. Despite the satisfactory appearance of the water surface in the area usually occupied by the eddy, considerable erosion occurred below the cofferdam. Also, the cofferdam was undermined to a degree that would make its stability questionable.

An attempt was then made to reduce the erosion by lengthening the specification bucket so that the jet was thrown considerably further downstream. The bucket was lengthened 150 feet, and sloped upward, but the resulting operation was still unsatisfactory. The eddy persisted and the resulting erosion was excessive.

Finally, the specification bucket was reinstalled in the model for further development and testing, since it appeared to show most promise hydraulically, and from an economic standpoint appeared to be the cheapest to construct. With ultimate tailwater and the cofferdam in place, the operation appeared improved. The deep erosion hole was moved downstream where it was of less concern, but the cofferdam was undermined somewhat on the apron side. Some erosion also occurred in the powerhouse tailrace.

From tests on the sand used to represent the prototype riverbed, it was found that the sand, after compaction, eroded readily at a velocity corresponding to 3 feet per second prototype. Also, the sand slumped badly when wet and it was felt that the erosion in the model was excessive for these reasons.

To more fully understand the type and amount of erosion that would actually take place in the prototype, the model bed was molded of a mixture of Lumnite cement and sand that would erode at a predetermined velocity. Estimates of the ability of the prototype bed material to resist erosion were made and sand-cement mixtures were developed to resist erosion to a similar degree in the model. It was estimated that the rock outcroppings on the right and left banks would withstand a velocity of 14 to 16 feet per second before erosion started and that the riverbed material would withstand 7 to 8 feet per second. With these calibrated mixtures in place, testing was resumed. Indications were that with present tailwater conditions, the eddy was not dangerous. Areas that had been badly eroded when loose sand was used for riverbed material were untouched by erosion when the stabilized sand was used.

For ultimate tailwater tests, the riverbed was molded in stabilized sand 15 feet lower than for the tests using present tailwater conditions. The eddy was more in evidence but did not cause serious damage close to the bucket for high discharges. Of more concern in these tests was the eddy formation in the bucket itself for discharges up to 50,000 second-feet. Erosion tests showed that for these lower discharges, the ground roller was not sufficiently developed to bring material back against the sill and tendencies toward undermining of the sill were present, probably caused to some extent by the eddies in the bucket. At discharges above 50,000 second-feet, the ground roller caused eroded material to be deposited in the areas close to the sill that were eroded by the smaller discharges.

Although the operation of the specification bucket is unsatisfactory in some respects, it is the opinion of the Hydraulic Laboratory staff, shared by Messrs. McConaughy and Hoffman, that the specification bucket

is the most promising of all the designs tested. It is believed that training walls on the apron, a cofferdam along the line of the right training wall, or a diagonal spur dike between the right training walls and the powerhouse, or some combination of these will sufficiently improve the operation of the specification bucket to make its performance satisfactory. Tests to determine the effects of these structures are now in progress.

A comparison of costs of the various buckets tested is shown in the following table:

DAVIS DAM--SPILLWAY
Cost Comparisons--Spillway Bucket Studies

(Scheme numbers correspond to test numbers)

| Scheme | Description | Additional cost over Scheme 1* |
|---|---|---|
| 1 | Specification bucket | - |
| 2 | Jump pool, floor at elevation 460 | $1,330,000 |
| 2-A** | Jump pool, floor at elevation 454 | 1,560,000 |
| 5 | Free jump pool 75 feet R, lip at elevation 515 | 330,000 |
| 6 | Angostura type bucket, invert at elevation 440 | 1,930,000 |
| 7 | Angostura type bucket, invert at elevation 470 | - |
| 8 | Lengthened specification bucket | 800,000 |

*Field cost. Does not include contingencies of overhead.

**Not tested or shown.

## DESCRIPTION OF TESTS

### General Information

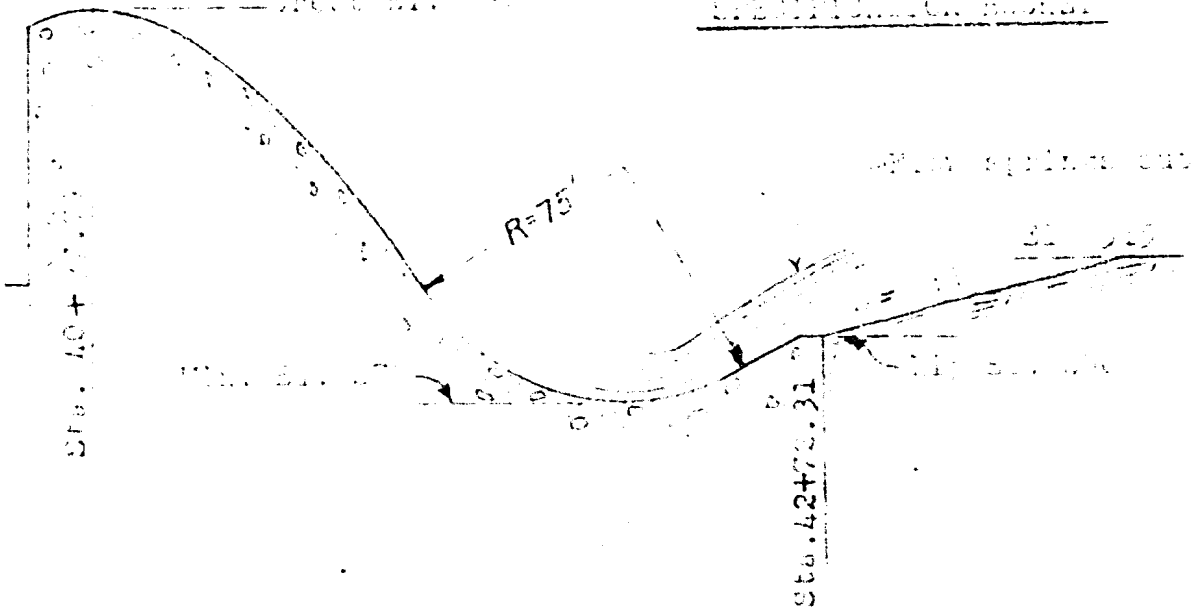
Except for Tests 9 and 10, erosion tests were made using sand, which, under actual test, began to erode at a velocity corresponding to 3 feet per

second (prototype). The length of each test is noted but, in general, was either of 2- or 7-hour duration. The 2-hour tests indicate the general trend of the erosion and, for preliminary investigation, supply all the necessary information. Slightly deeper erosion was usually found after 7 hours of operation, but the general pattern remained the same.

Arrows and numbers on the erosion test photographs show the direction and amount of velocity measured during the test run.

Tests 9 and 10 were made using stabilized sand to represent the prototype riverbed. To determine the proper proportions of the final mixture, trial mixtures were made, cured, and exposed to the erosive action of a jet of water whose velocity was known. A mixture of 1 part Lumnite cement to 110 parts of sand was found to erode at a velocity corresponding to 8 feet per second (prototype). A mixture of 1 part Lumnite cement to 75 parts of sand was found to erode at a velocity corresponding to 15 feet per second (prototype). In both cases, proportions were by weight and the mixtures were used in Tests 9 and 10.

The material contained in this discussion includes only the significant tests and does not mention other tests which appeared to be important at the moment but did not prove of value in obtaining an answer to the problem. The following pages substantiate and illustrate the test results previously summarized. Details of the buckets and aprons tested, test data, operating conditions, and appropriate comments are included on the sheets preceding the photographs.

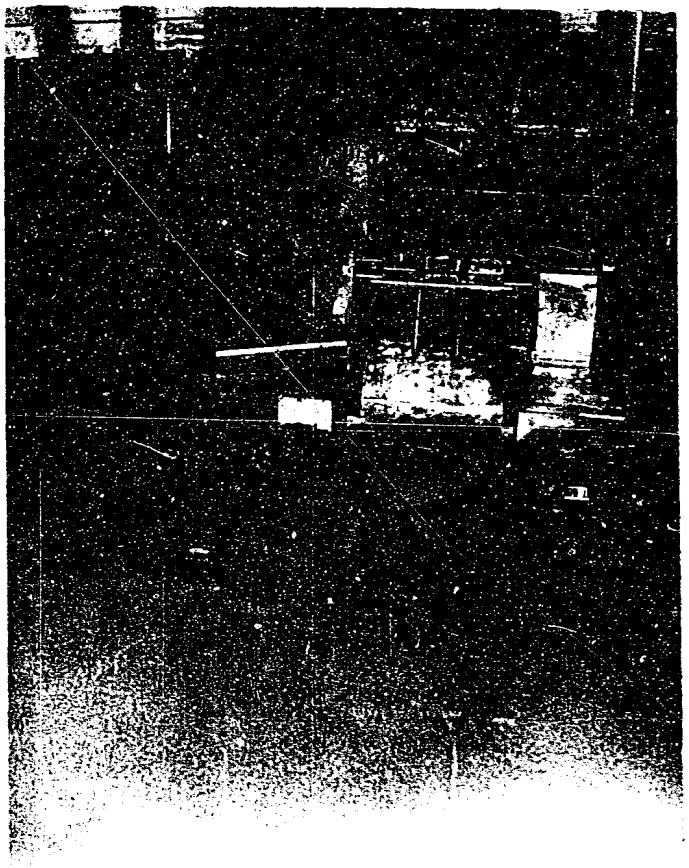



Test No. 1

Discharge----------,000 second-feet

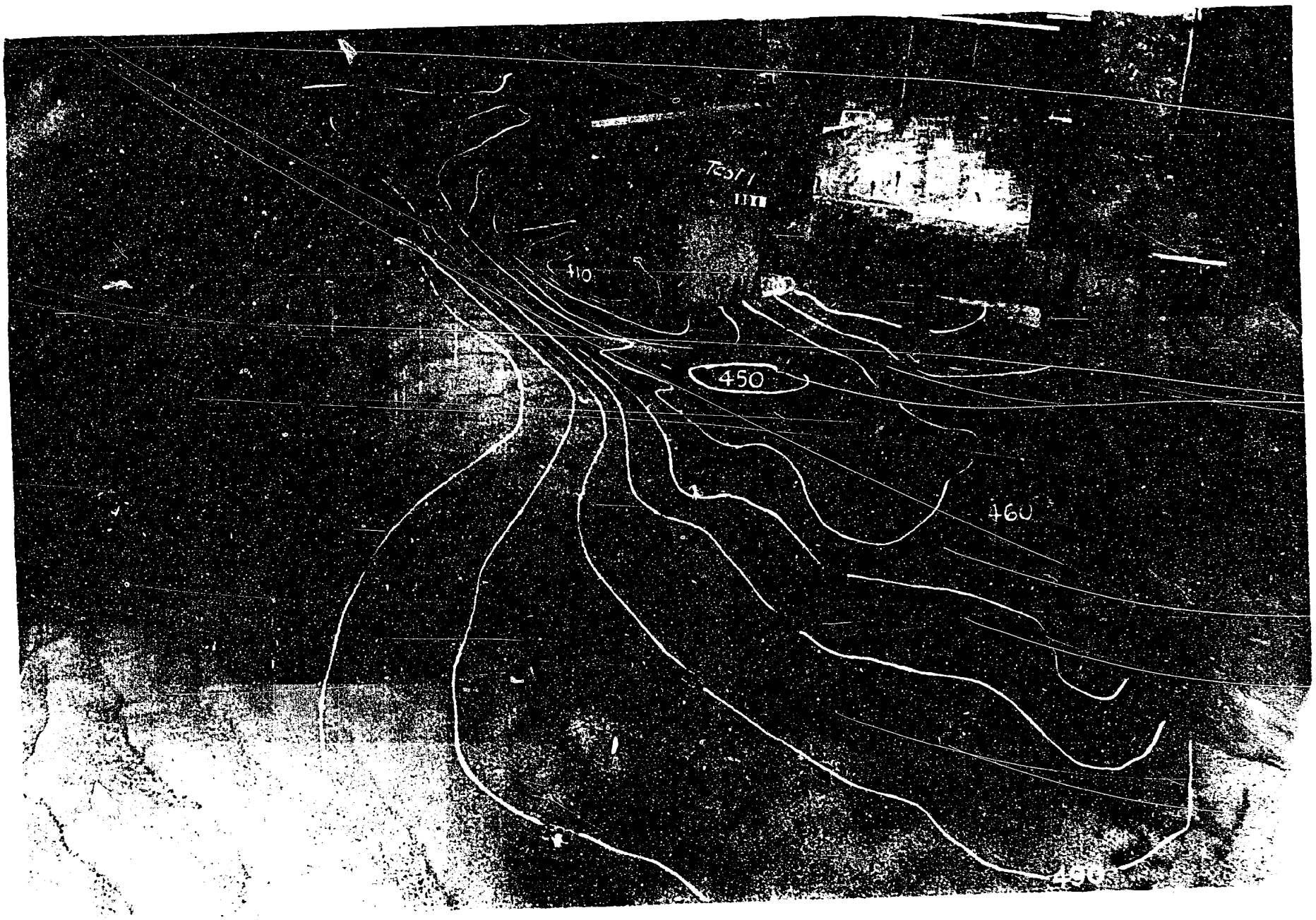
Tailwater---------533 (Present Elevation)

Length of Test----6 hrs. 55 min.



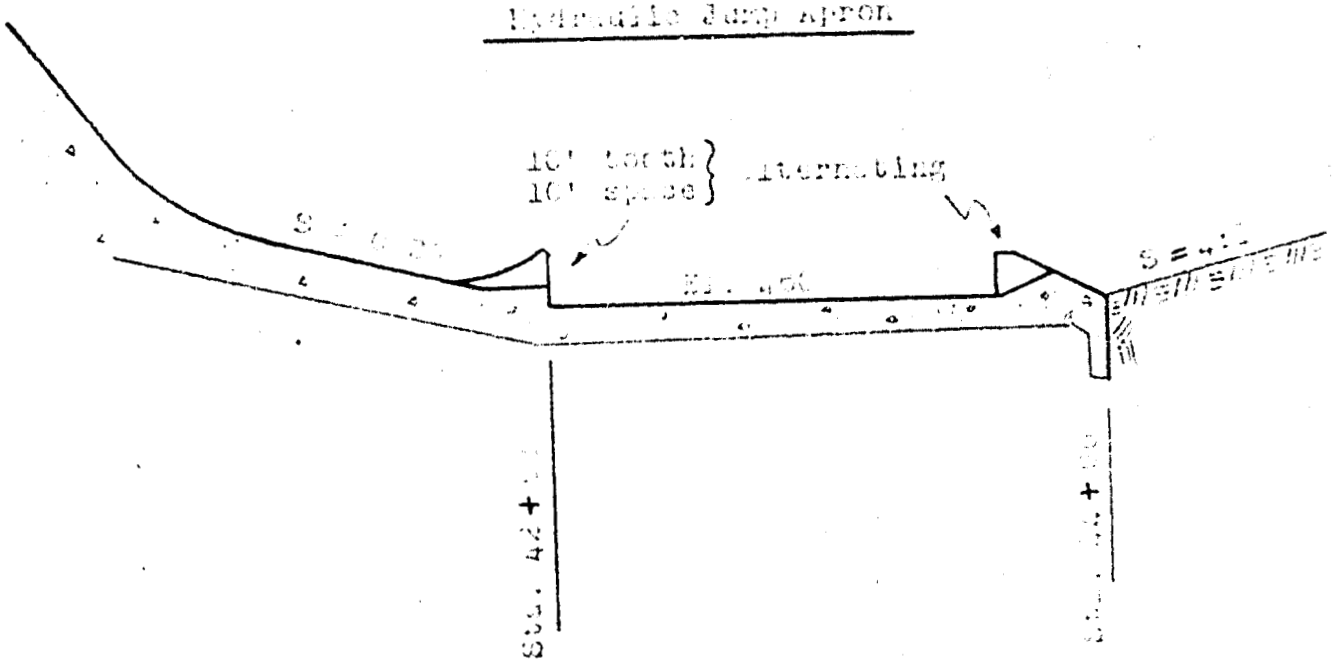
Appearance of Model Bed
before Test No. 1

Results of Erosion Test are shown below


Test 1
410
450
460

Test No. 2

Interchangeable Jump Apron




Test 2

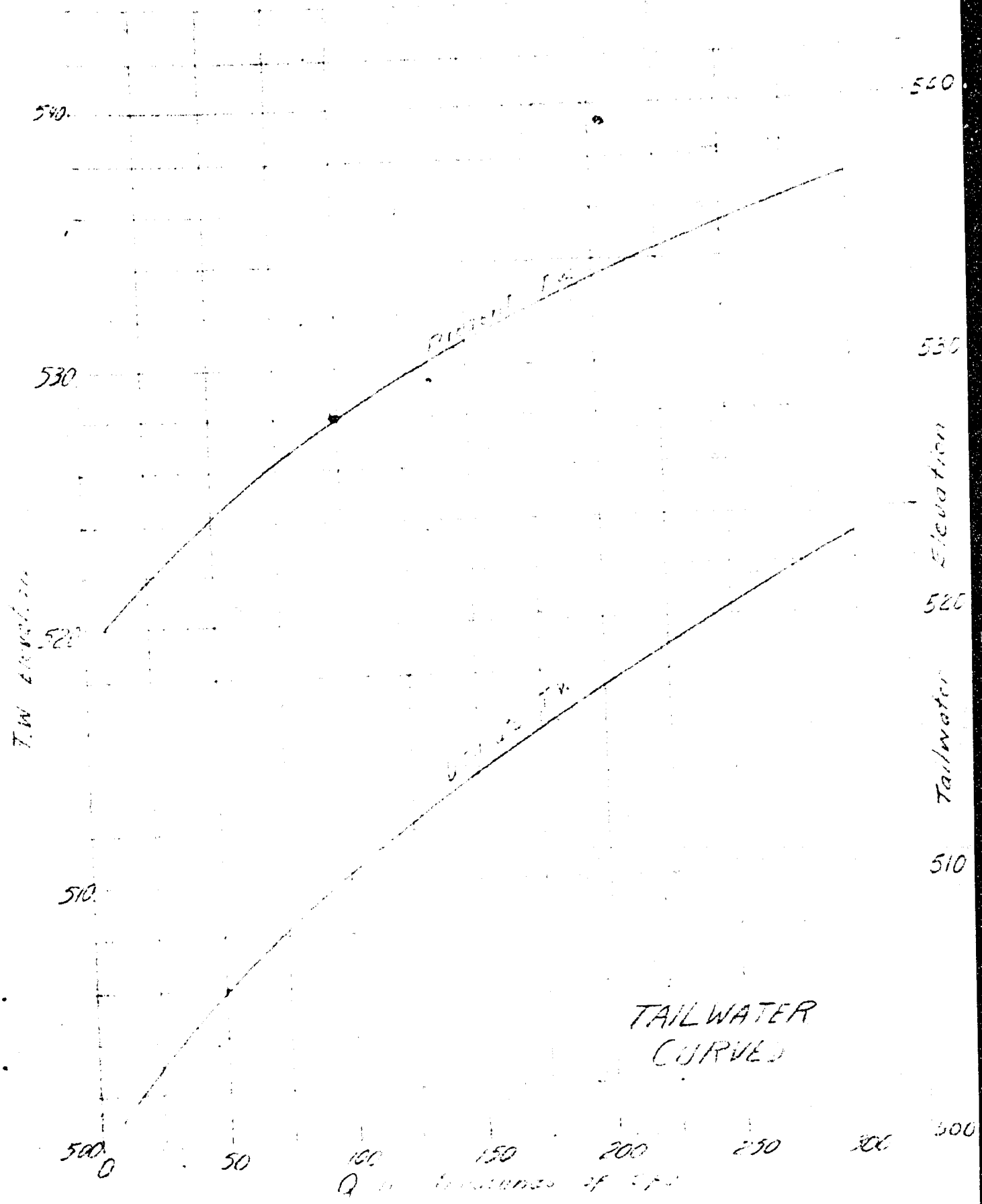
Discharge - 200,000 sec.-ft.
Tailwater - present -- Elev. 531.5
Time of Test - 6 hrs. 55 min.

Notes:
Apron did not have sufficient length to hold jump on apron for both present and ultimate tailwater elevations for all discharges.

The table below shows the elevation at which the jump was swept out of the apron and the elevation to which the tailwater had to be raised to force the jump to move back onto the apron. Also shown are the present and ultimate tailwater elevations for the discharges tested.

| Operating Condition | Discharges in second feet | | | |
|---|---|---|---|---|
| | 250,000 | 200,000 | 100,000 | 50,000 |
| Jump Sweeps Out | 532.5 | 514.5 | 503.5 | 479 |
| Jump Moves Back | 528.5 | 510.5 | 500.0 | 479 |
| Present T.W. El. | 535.5 | 533.5 | 528.0 | 524 |
| Ultimate T.W. El. | 529.5 | 527.0 | 521.5 | 509 |


490
450
480


540
530
520
510
500
0
50
100
150
200
250
300
550
530
520
510
Tailwater Elevation
TAILWATER
CURVE

Test No. 3

SPECIFICATION BUCKET

Details shown for Test No. 1

Notes:

This test differed from Test No. 1 in that the sand area between right training wall and powerhouse was molded in non-erodible concrete using rock contours obtained from field data. Also at this time the maximum discharge for design purposes was reduced from 300,000 to 175,000 second-feet.

Results of erosion test are shown below. Rocks in the bottom of the erosion hole are remnants of dikes used in an attempt to reduce the eddy action in a previous test.

Test No. 3

Discharge - 175,000 sec.-ft.
Tailwater - Present - El. 532.75
Time of Test - 8 hrs.


510

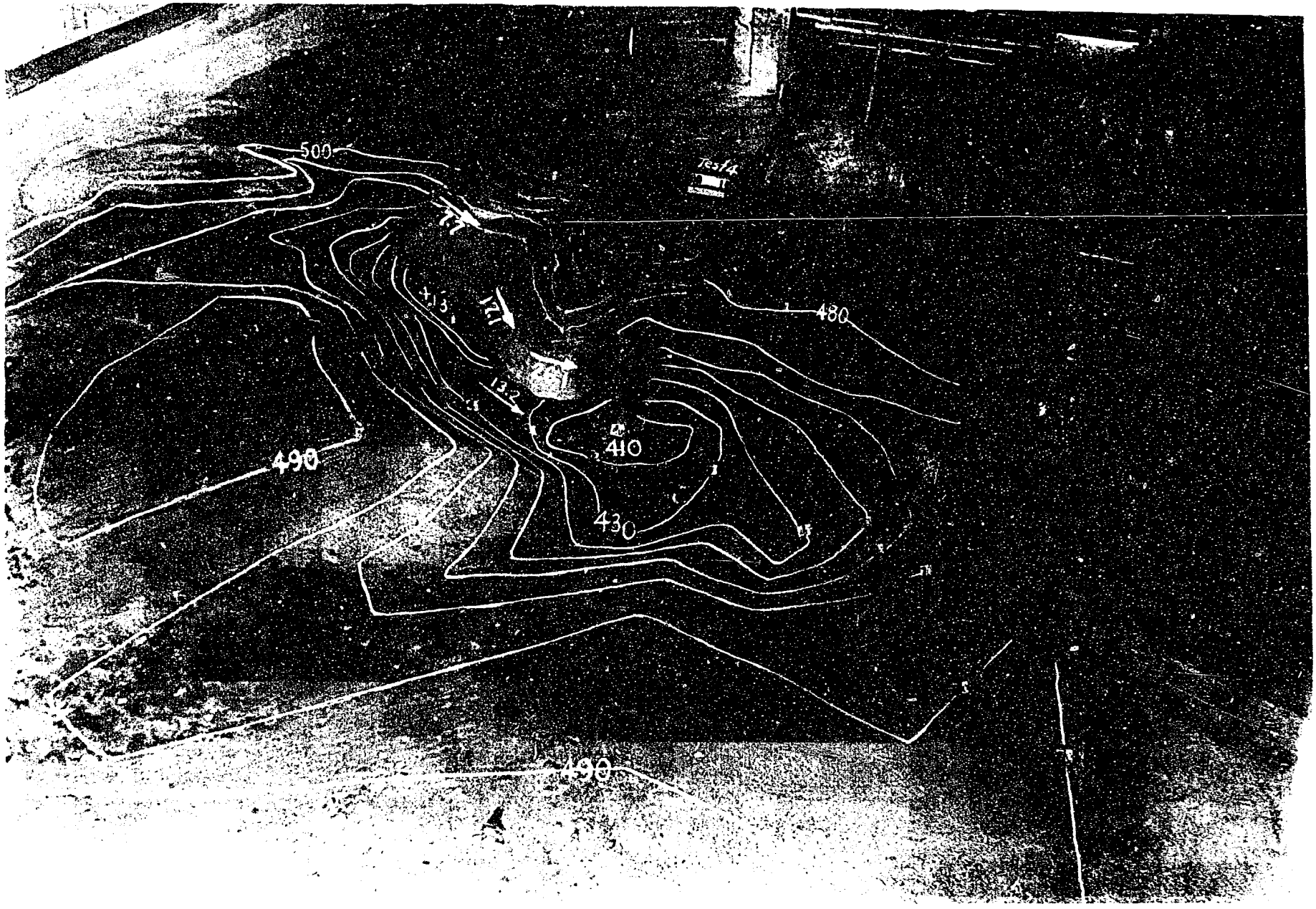
## Test No. 4.

Same as Test No. 3 but with ultimate tailwater at El. 515.75. Erosion for this test was considerably greater along rock on right side and 10 feet deeper at lowest point.

Test No. 4

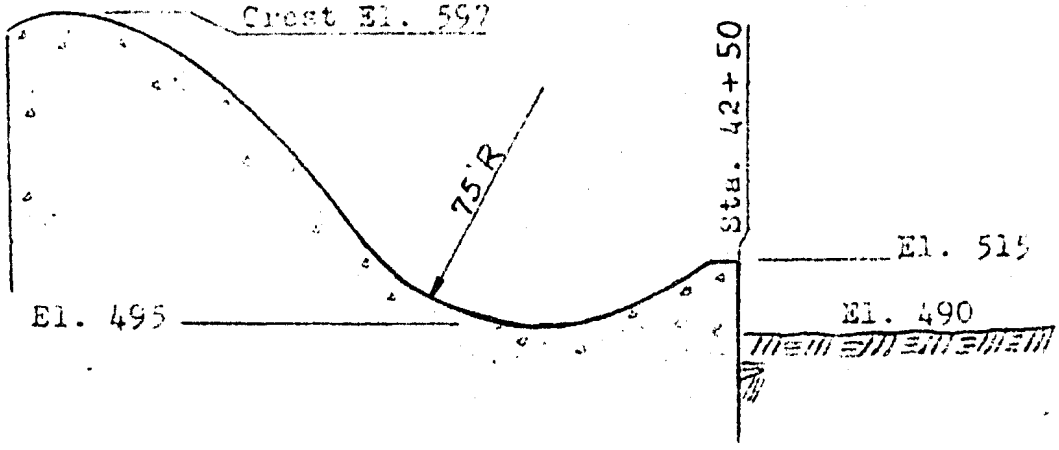
Discharge - 175,000 sec.-ft.
Tailwater - Ultimate - El. 515.75
Time of Test - 8 hrs.

Results of the erosion test are shown below.


500
490
480
410
430
490

Test No. 5
SPECIFICATION BUCKET AT HIGH ELEVATION

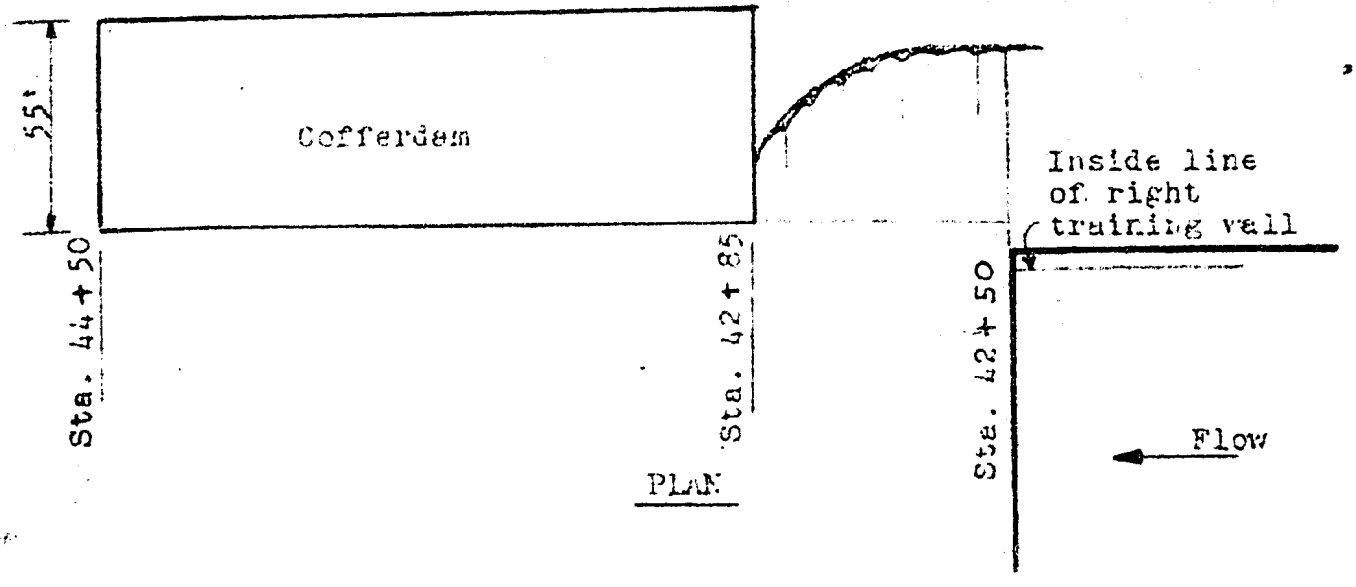
Following a series of visual short duration tests, using the specification bucket, with lip elevations between 490 and 515, it was decided to make long duration tests with the bucket lip at elevation 515 for both present and ultimate tailwater conditions.

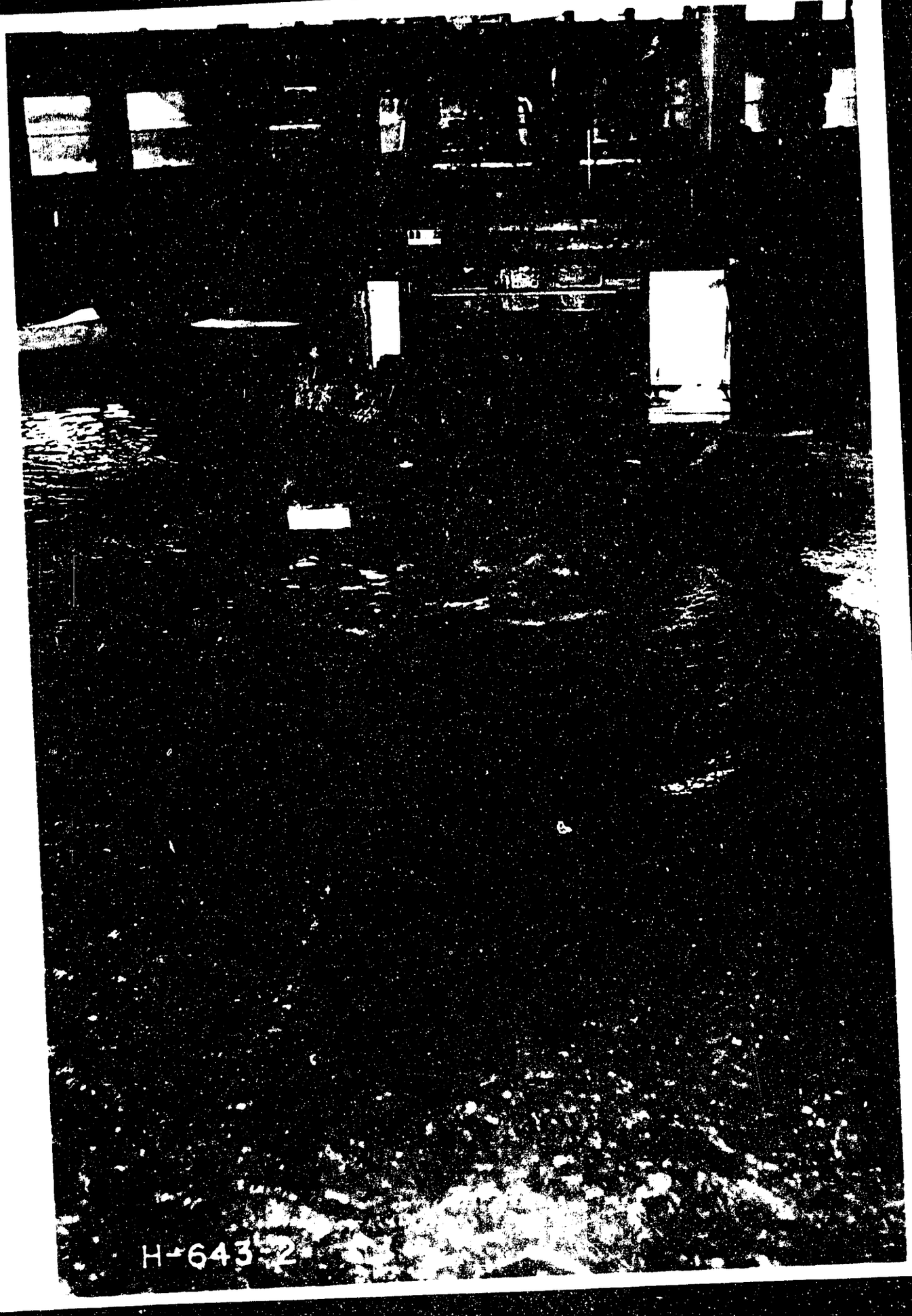


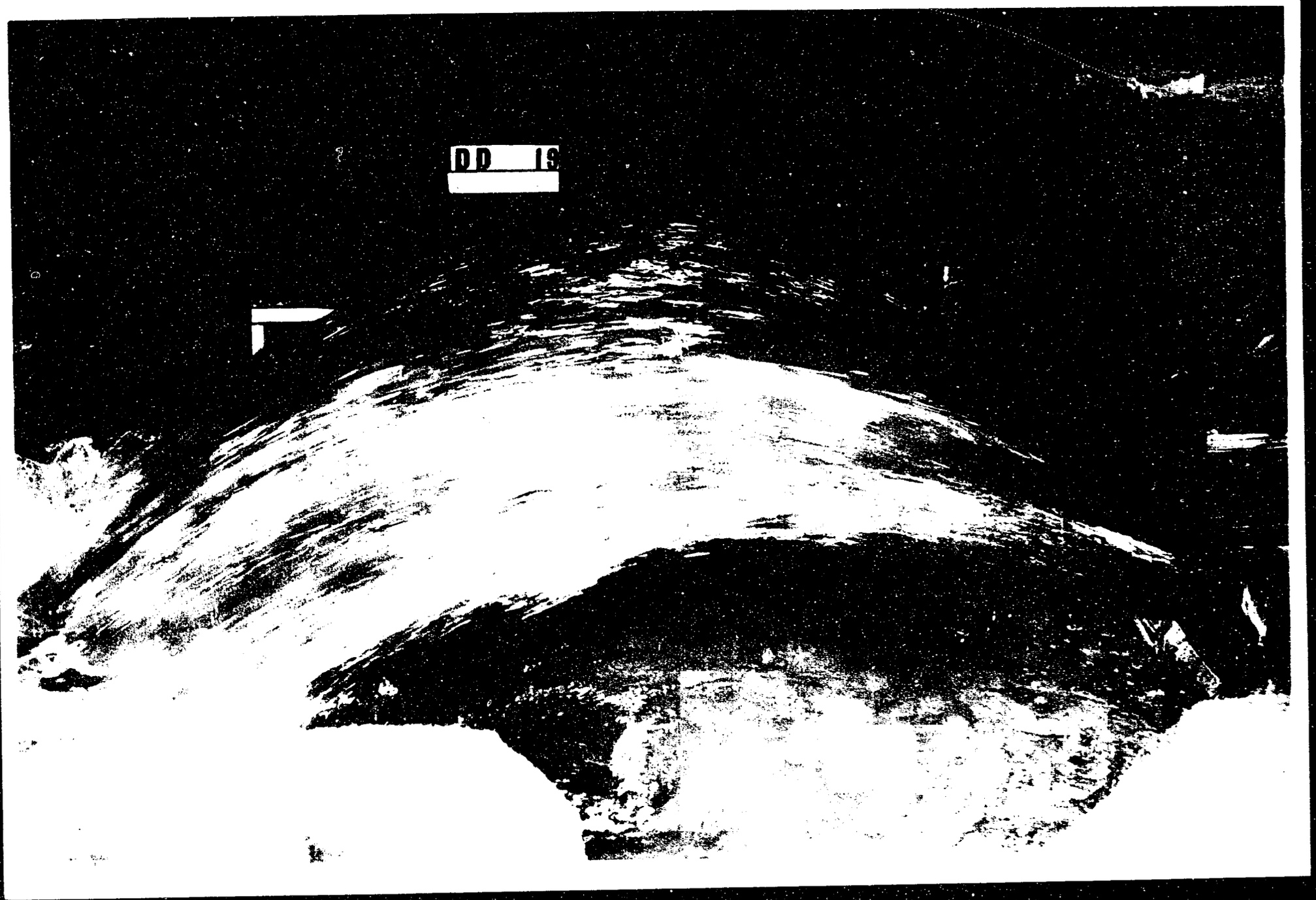

Photographs on the two following pages show the operation of this bucket, first in general, then in detail. The third photograph shows the results of erosion test 5. The cofferdam along the line of the right training wall was installed in the model since it appeared to reduce the eddy in the dead water area.

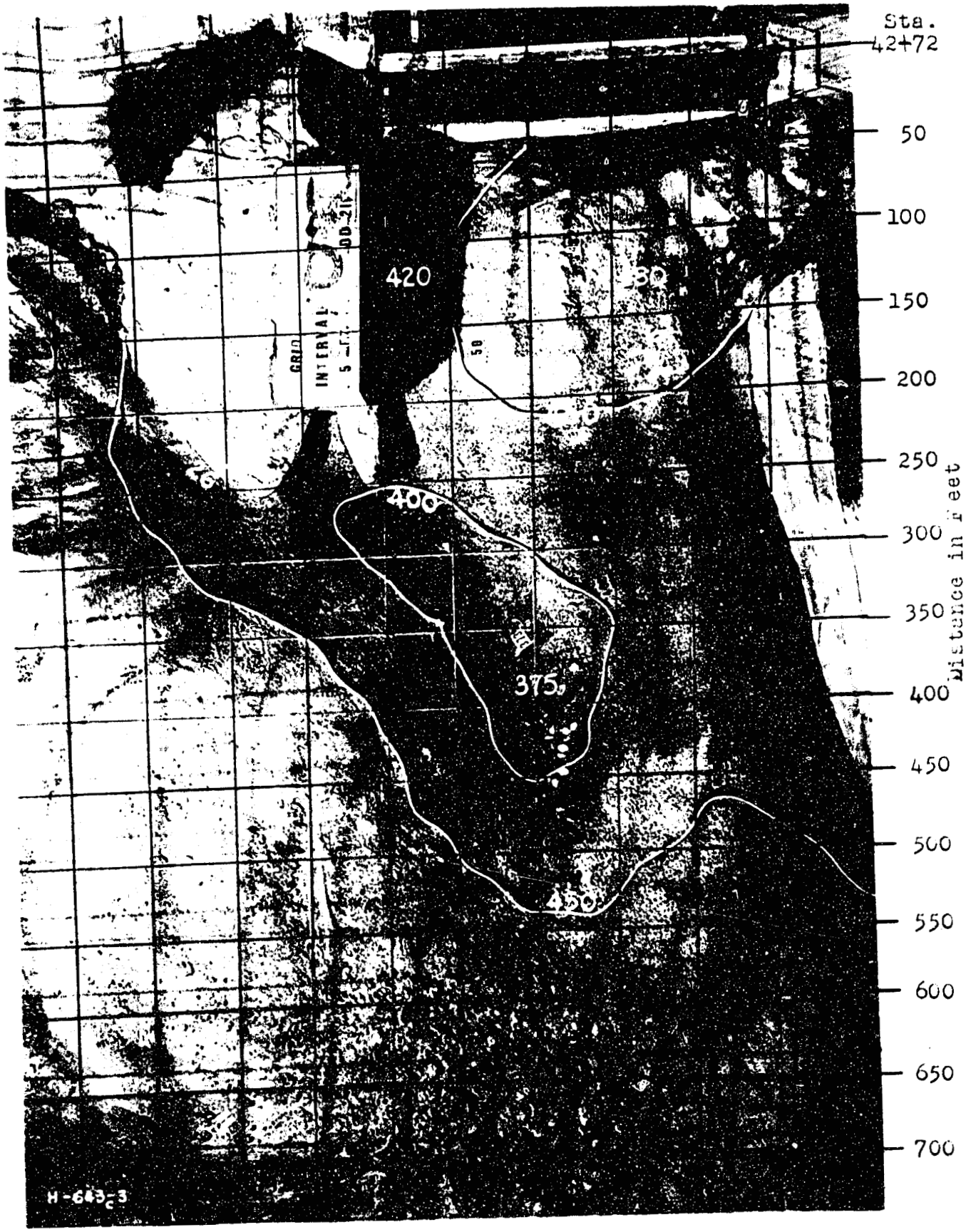
Test No. 5

Discharge-175,000 sec.-ft.
Tailwater-Ultimate-El. 515.75
Time of Test-2 hrs.




H-643-2

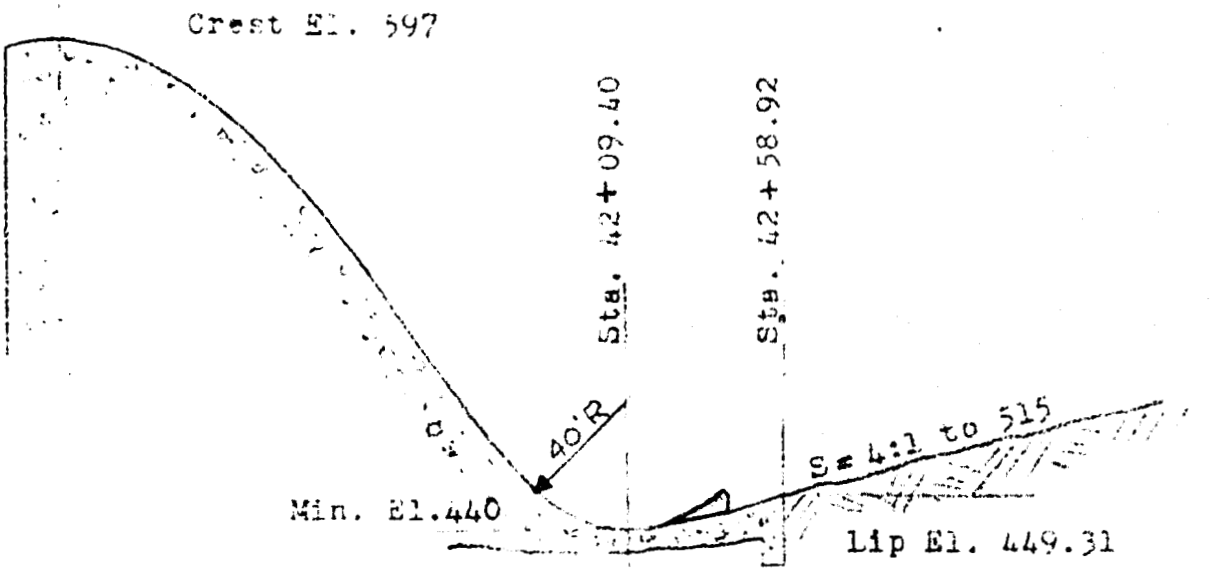

DD 15


Sta.
42+72
50
100
150
200
250
300
350
400
450
500
550
600
650
700
Distance in Feet
420
30
400
375
450
GRID INTERVAL
H-643-3

Test No. 5

Test No. 6

DEEP ROLLER BUCKET (ANGOSTURA TYPE)



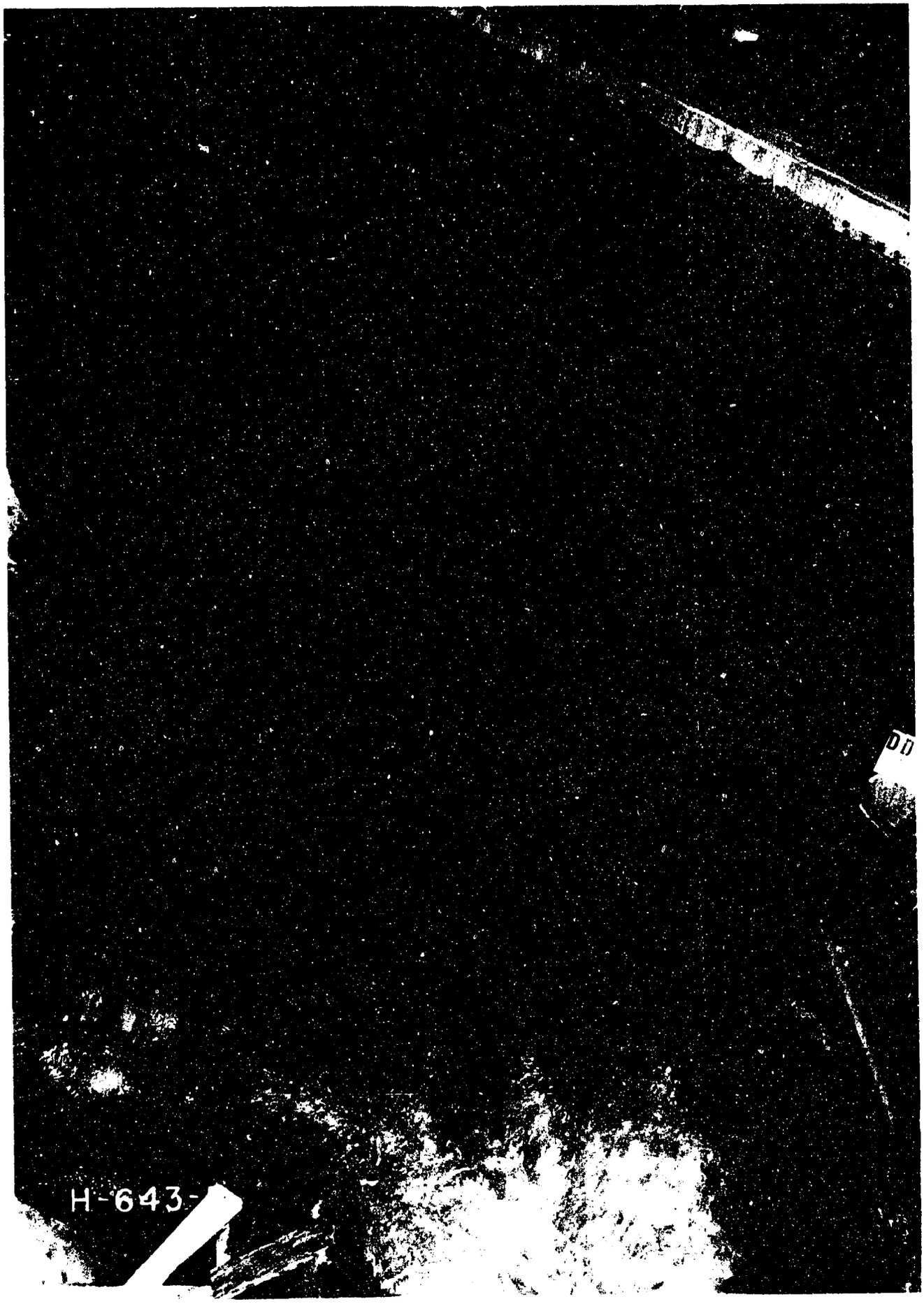

Angostura Type Bucket

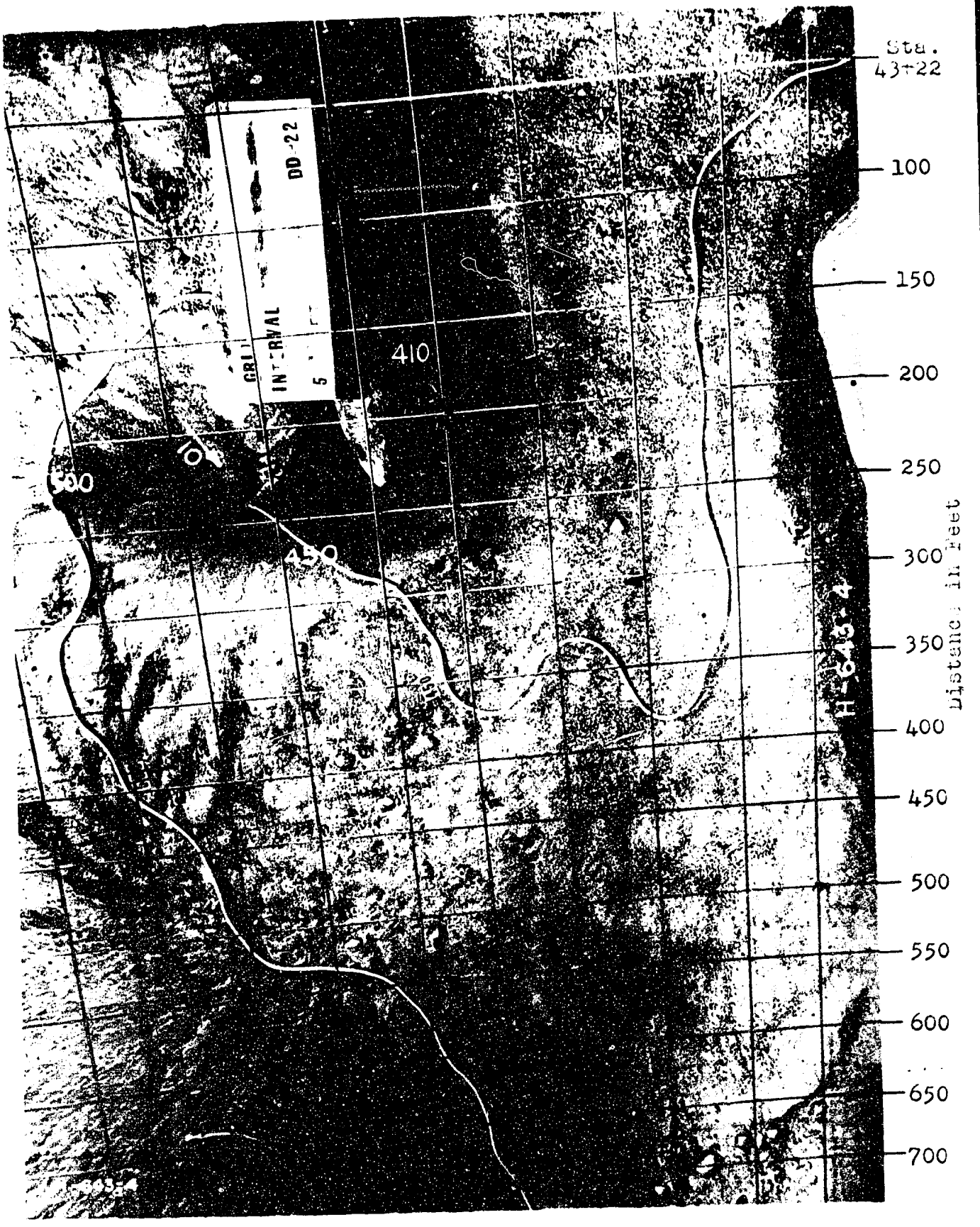
Test No. 6

Discharge - 175,000 sec.-ft.
Tailwater - Ultimate - El. 515.75
Time of Test - 2 hrs.

Notes:

With this low bucket the roller action occurred for all discharges and tailwater conditions. The submerged action reduced the surface velocities in the eddy on the right side but some erosion was still evident and the cofferdam was undermined. Photographs on the following 2 pages show first, the action on and below the bucket and second, the results of erosion Test No. 6.

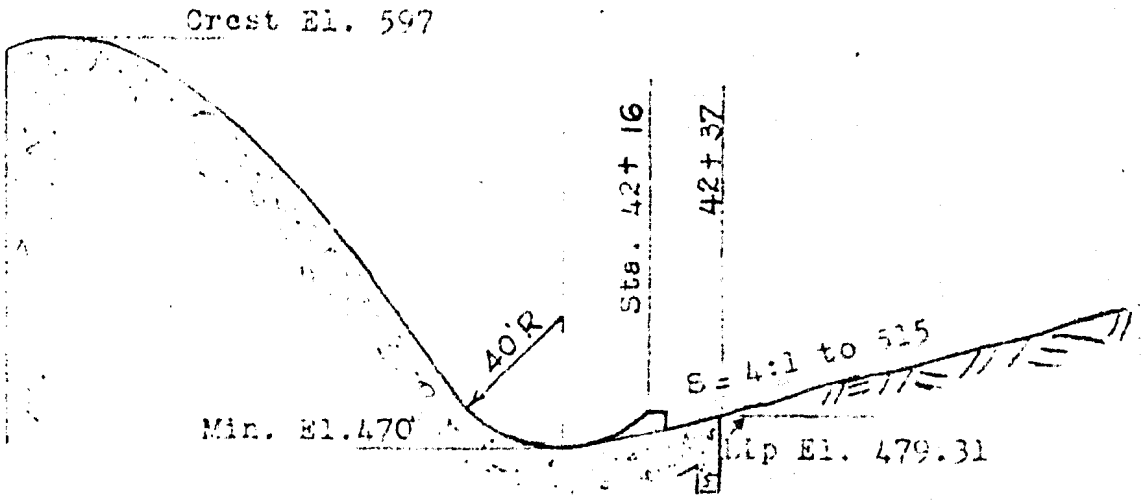

H-643-


Sta.
43+22
100
150
200
250
300
350
400
450
500
550
600
650
700
Distance in Feet
DD-22
410
530
450

Test No. 6

Test No. 7

ANGOSTURA TYPE BUCKET RAISED TO HIGHER ELEVATION



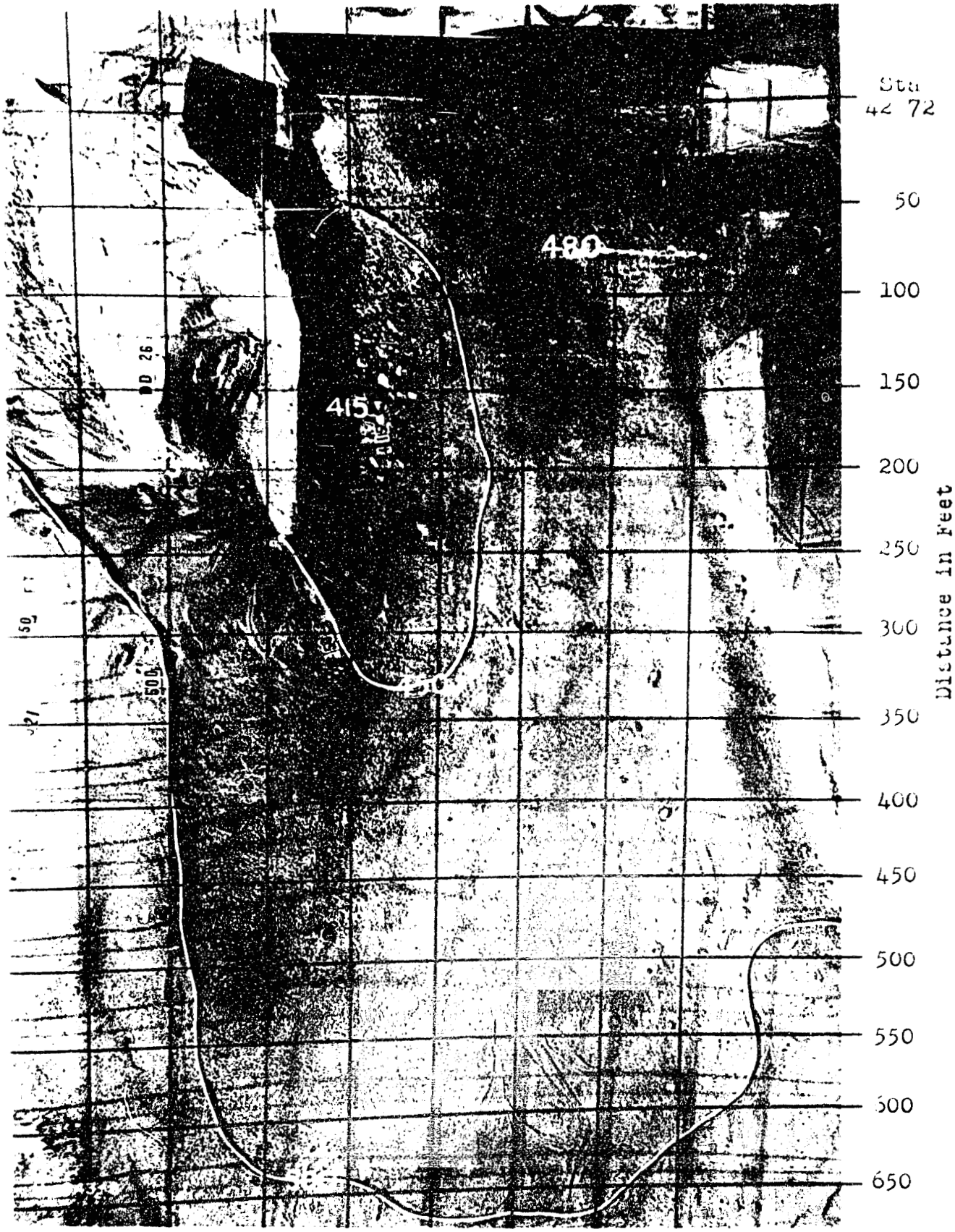

Since the Angostura type bucket had proved effective in preventing excessive erosion on other structures it was tested at the elevation shown. In this position the bucket fitted the existing foundation conditions to greater advantage.

The operation was similar to the specification bucket in that the water was thrown clear of the bucket for all conditions and no roller action occurred.

The resulting erosion is shown in the following photograph.

Test No. 7

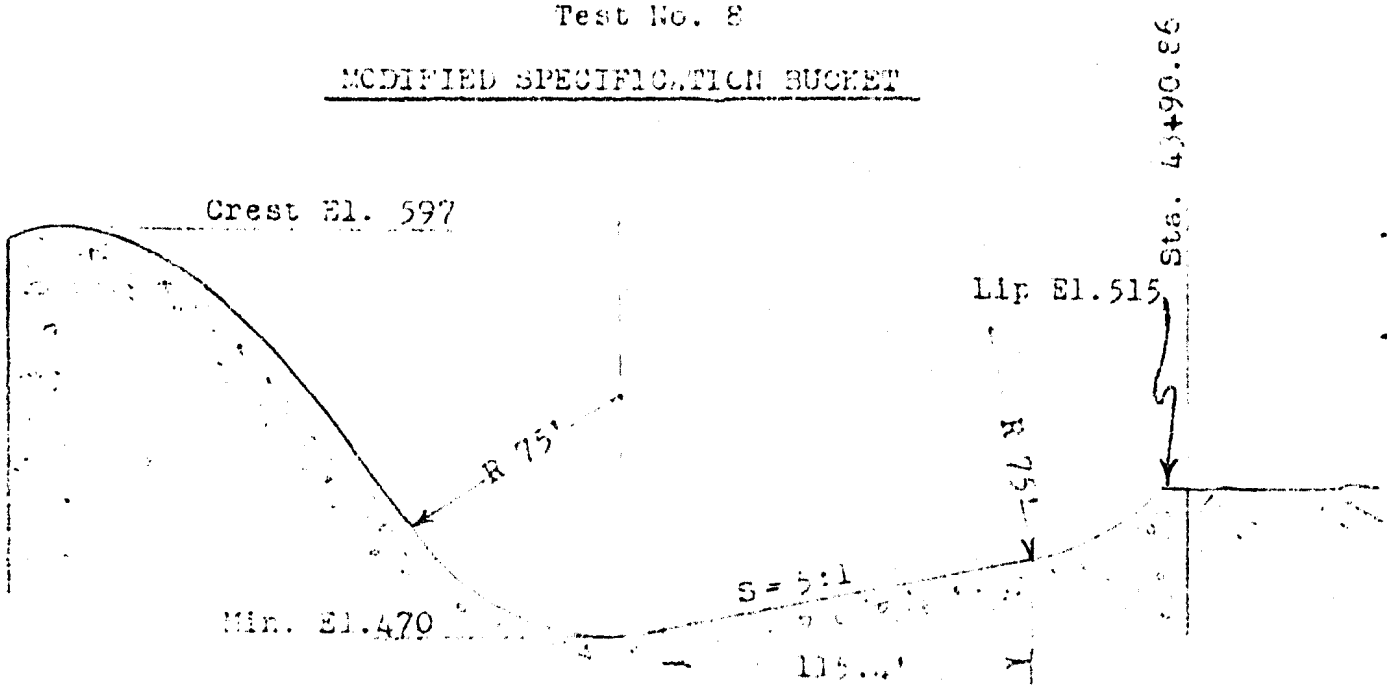
Discharge - 175,000 sec.-ft.
Tailwater - Present - El. 532.75
Time of Test - 2 hrs.


Sta
42 72
50
100
150
200
250
300
350
400
450
500
550
600
650
Distance in Feet
480
415

Test No. 7

Test No. 8

MODIFIED SPECIFICATION BUCKET



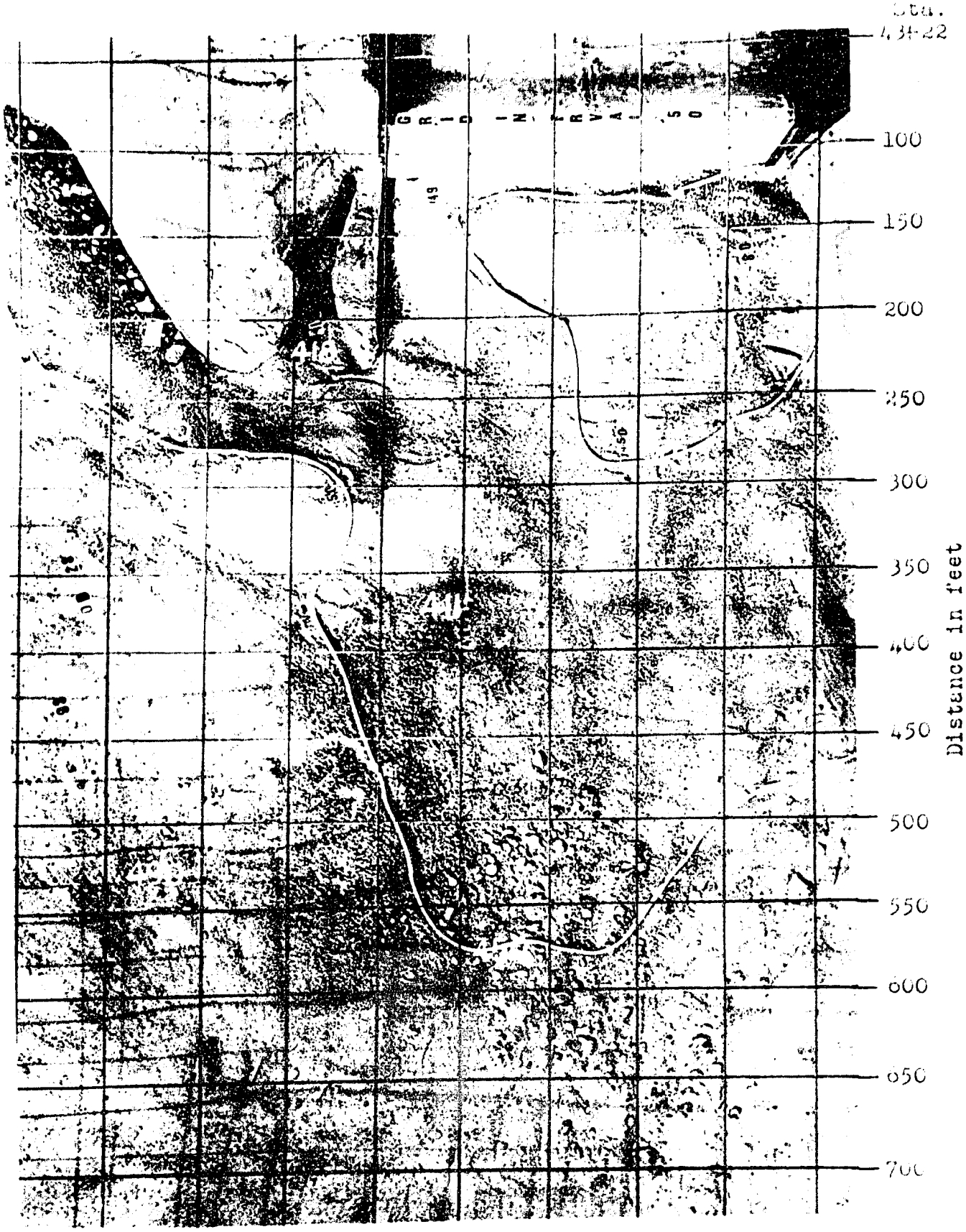

The specification bucket was modified as shown in order to "throw" the water downstream as far as was practical. This was done in an attempt to reduce the effects of the eddy on the right side.

The photograph on the opposite page shows the jet being "thrown" clear of the rock projection. The jet was not "thrown" far enough, however, to prevent the eddy from attaining a velocity of 16.2 ft. per second, prototype, and causing excessive erosion as shown in the second photograph.

Test No. 8

Discharge - 175,000 sec.-ft.
Tailwater - Ultimate - El. 515.7
Time of Test - 6 hrs. 30 min.


H-643-9
DD-21


Sta.
4,34-22
100
150
200
250
300
350
400
450
500
550
600
650
700
Distance in feet

Test No. 8

Test No. 9

Stabilized Sand Bed

SPECIFICATION BUCKET

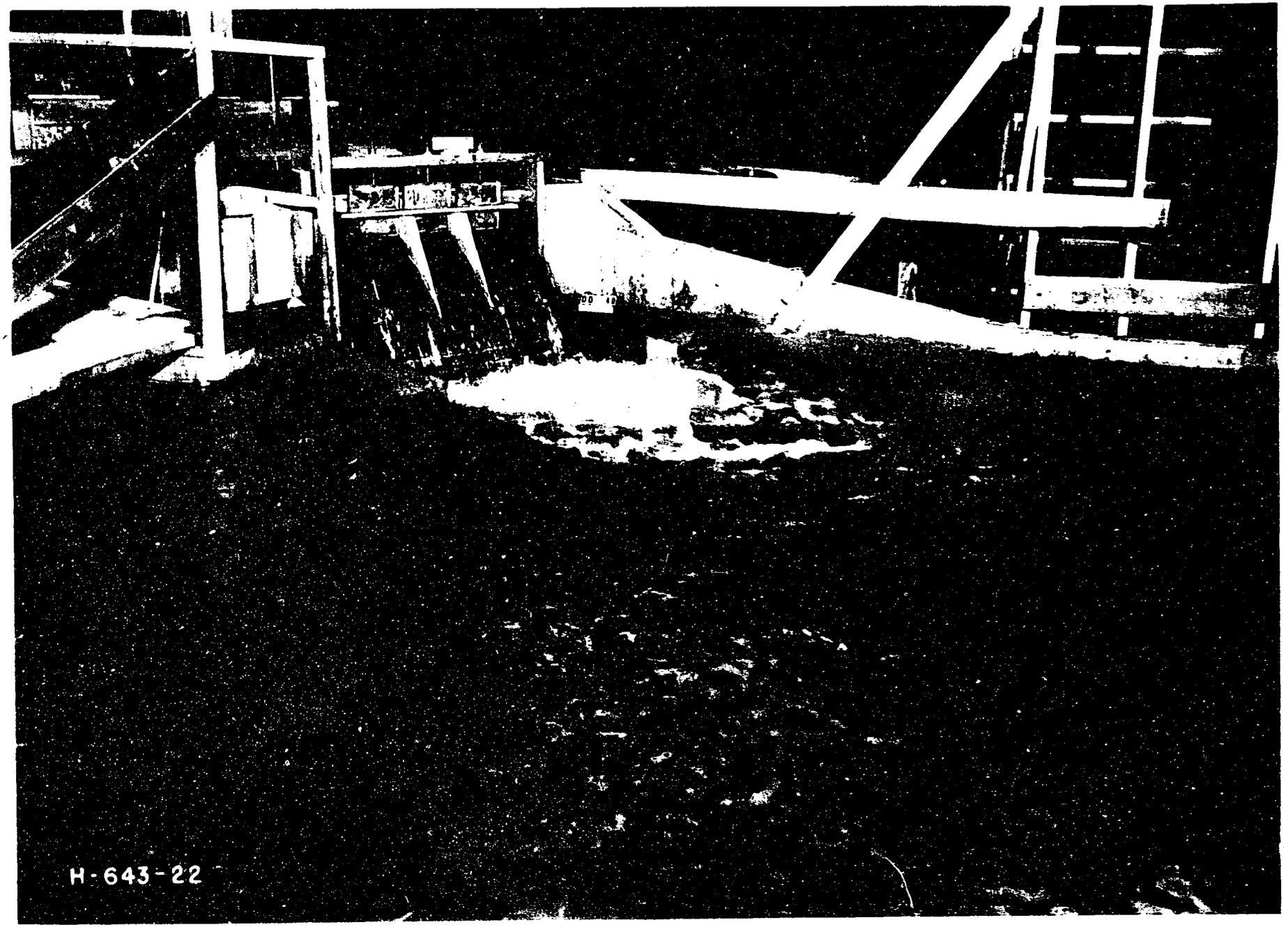
Details shown for Test No. 1

## Test No. 9

With the bed molded in stabilized sand at elevation 515, similar to that shown in the first photograph for Test 10, the discharge was gradually increased to 90,000 second-feet. The tailwater was set for present conditions, elevation 524. The resulting flow, shown in the following photograph, was entirely satisfactory and practically no erosion occurred after a one hour run. Because the flow did not sweep out of the bucket the eddy at the right training wall was hardly noticeable.

For 100,000 second-feet and tailwater elevation 526 flow and erosion conditions were similar. For 105,000 second-feet and tailwater elevation 531, shown in the second photograph, flow jumped clear of the bucket and some erosion occurred. Each discharge was tested for one hour and the bed was not remolded between runs. Erosion and eddy conditions were more severe, however for ultimate tailwater conditions shown in Test 10.

H-643-15


H-643-22

Test No. 10

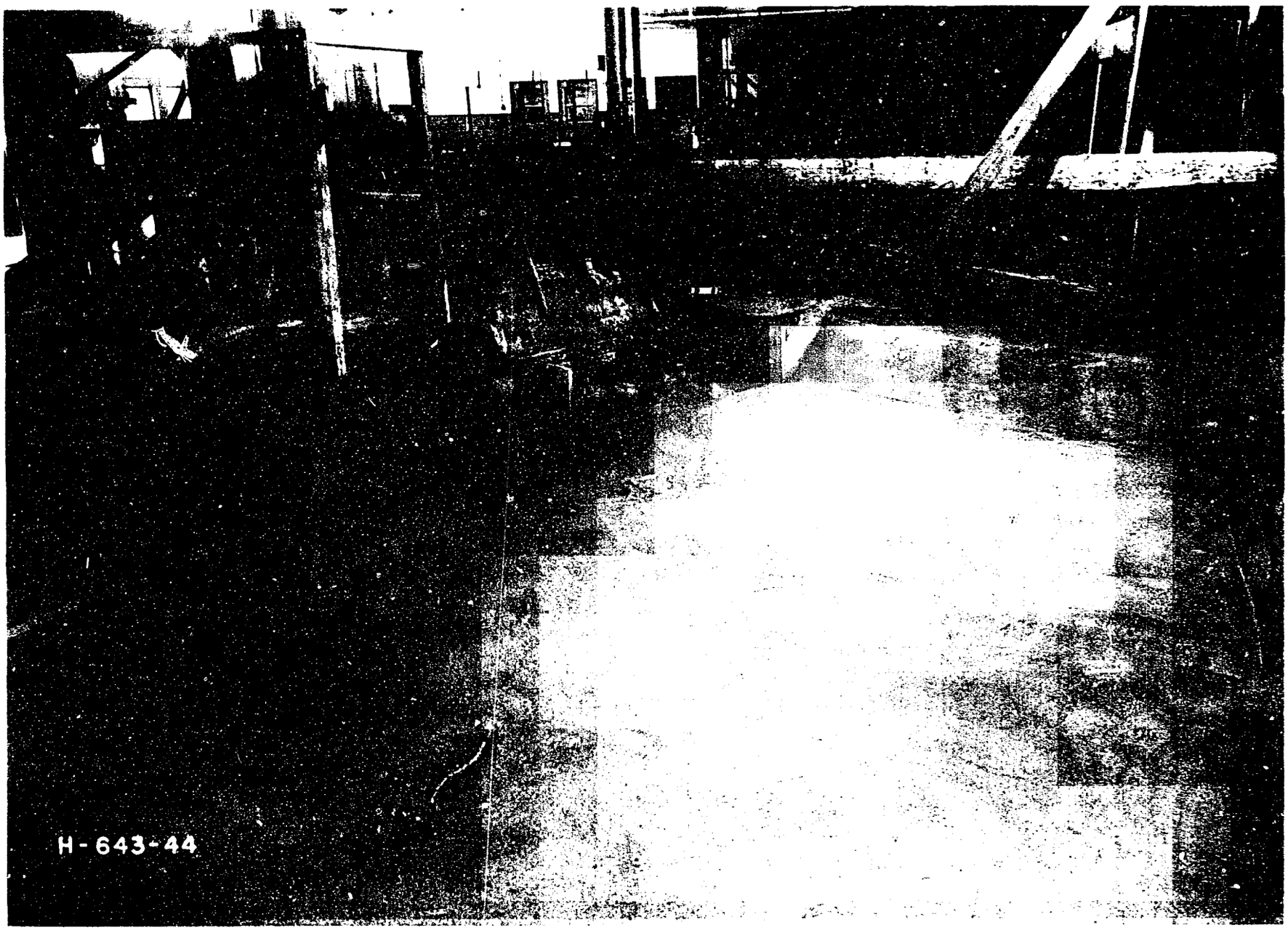
Stabilized Sand Bed

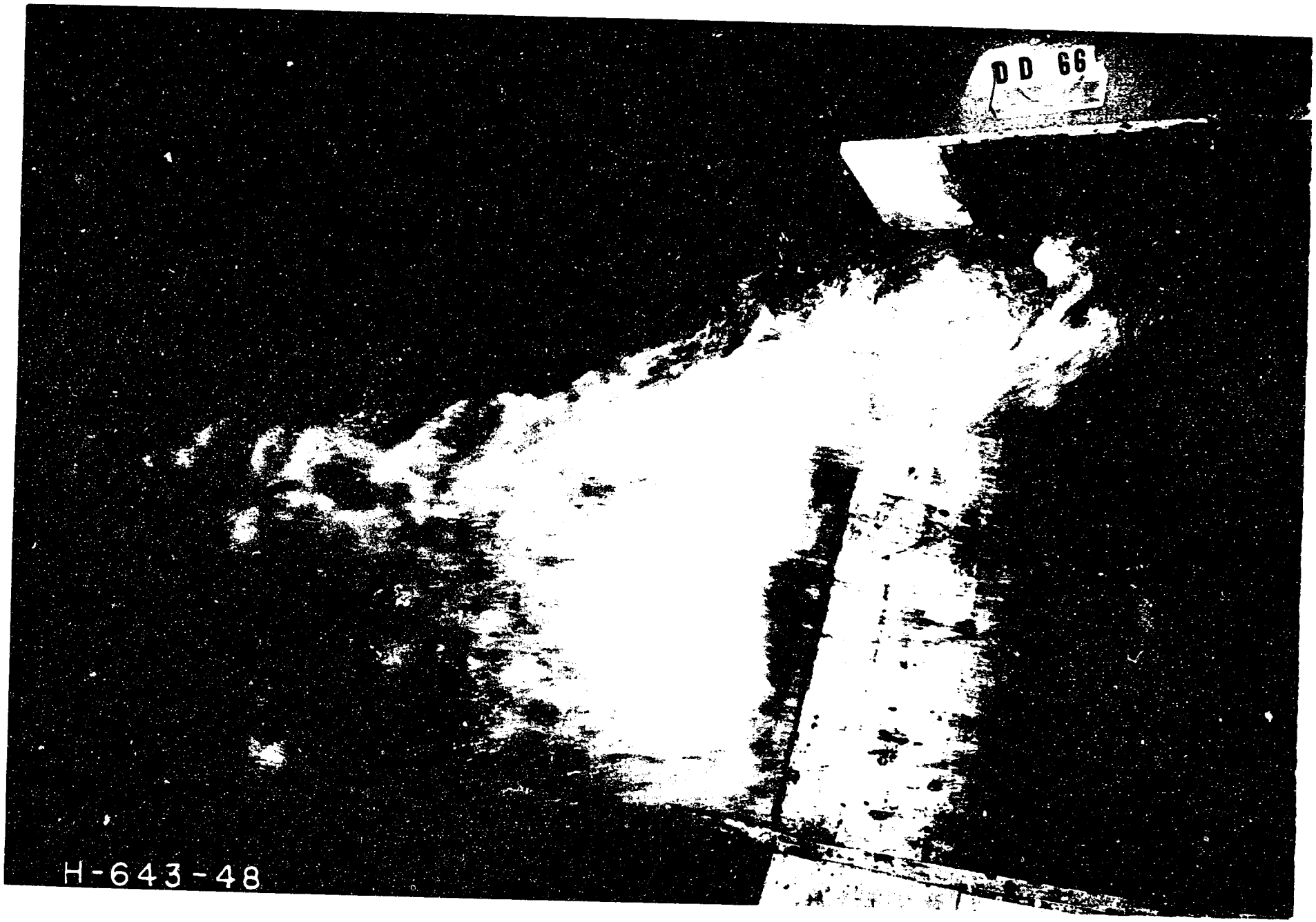
SPECIFICATION BUCKET

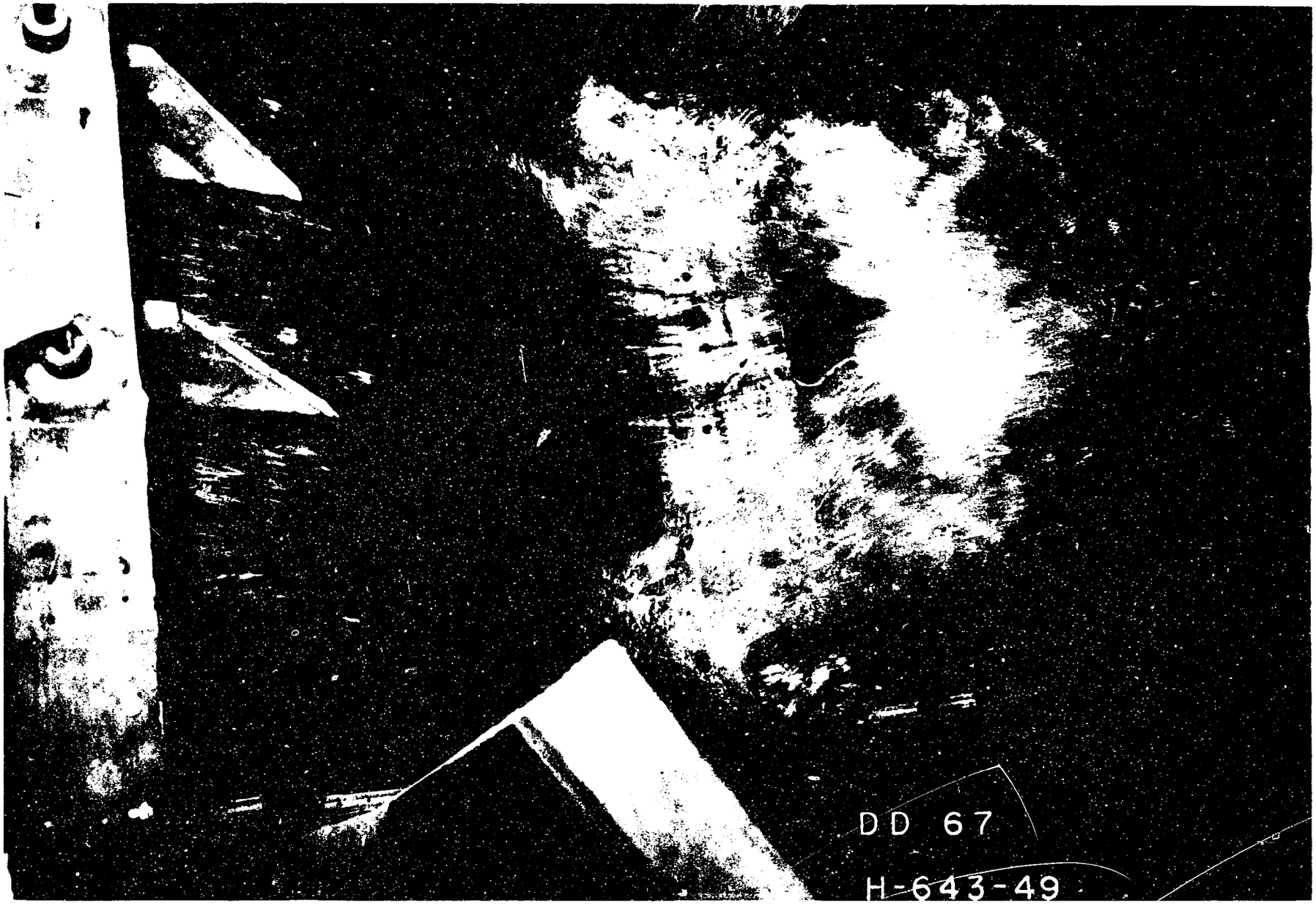
The bed was remolded after Test 9 in the flume and an elevation 515 as shown in the following photograph, (DD67). For 50,000 second-feet and ultimate tailwater elevation 505 an eddy formed in the bucket as shown in the second photograph, (DD68). For no apparent reason another eddy formed in the bucket for short periods of time as shown in the third photograph, (DD67). At the end of a one hour run the river bed was eroded as shown in the next photograph, (DD70).

Without remolding the bed a discharge of [illegible] second-feet was run for one hour with [illegible] tailwater at elevation 515 as shown in photograph DD71. The ground roller covered up the first hole in the bucket that had occurred during the 50,000 second-feet run as shown in photograph DD70.

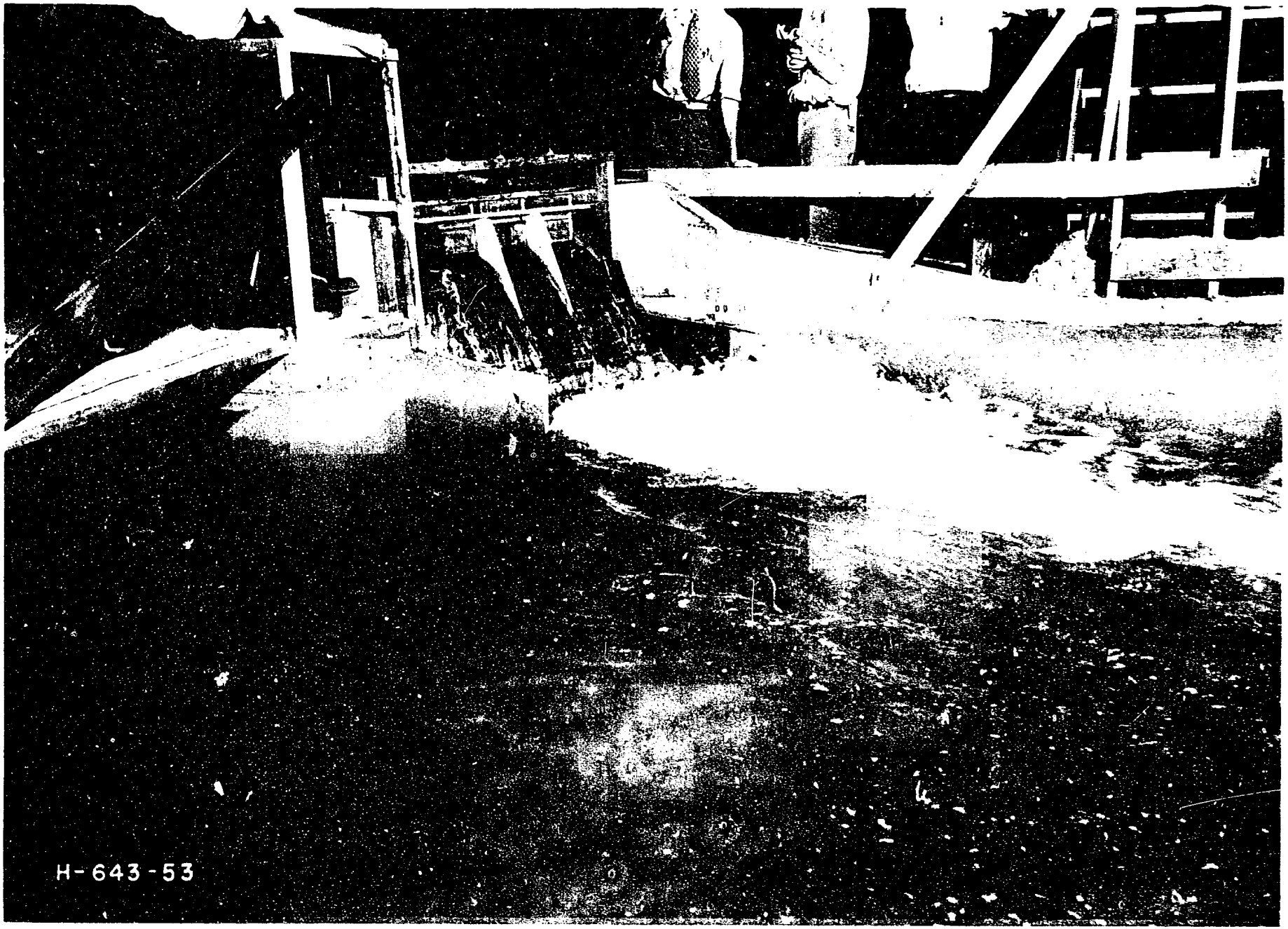
For [illegible] second-feet with ultimate tailwater elevation 515 the operation was as shown in photograph DD72. The velocity of the eddy in the foreground was estimated to be about [illegible] feet per second and caused very little erosion of the rock outer piers. The erosion after a one hour run at 175,000 second-feet, plus the effects of the 50,000 and 100,000 second-feet runs, is shown in photographs DD73 and DD74. The greatest erosion occurred below the rock projection on the right side and in the hill along the left bank.


H-643-44

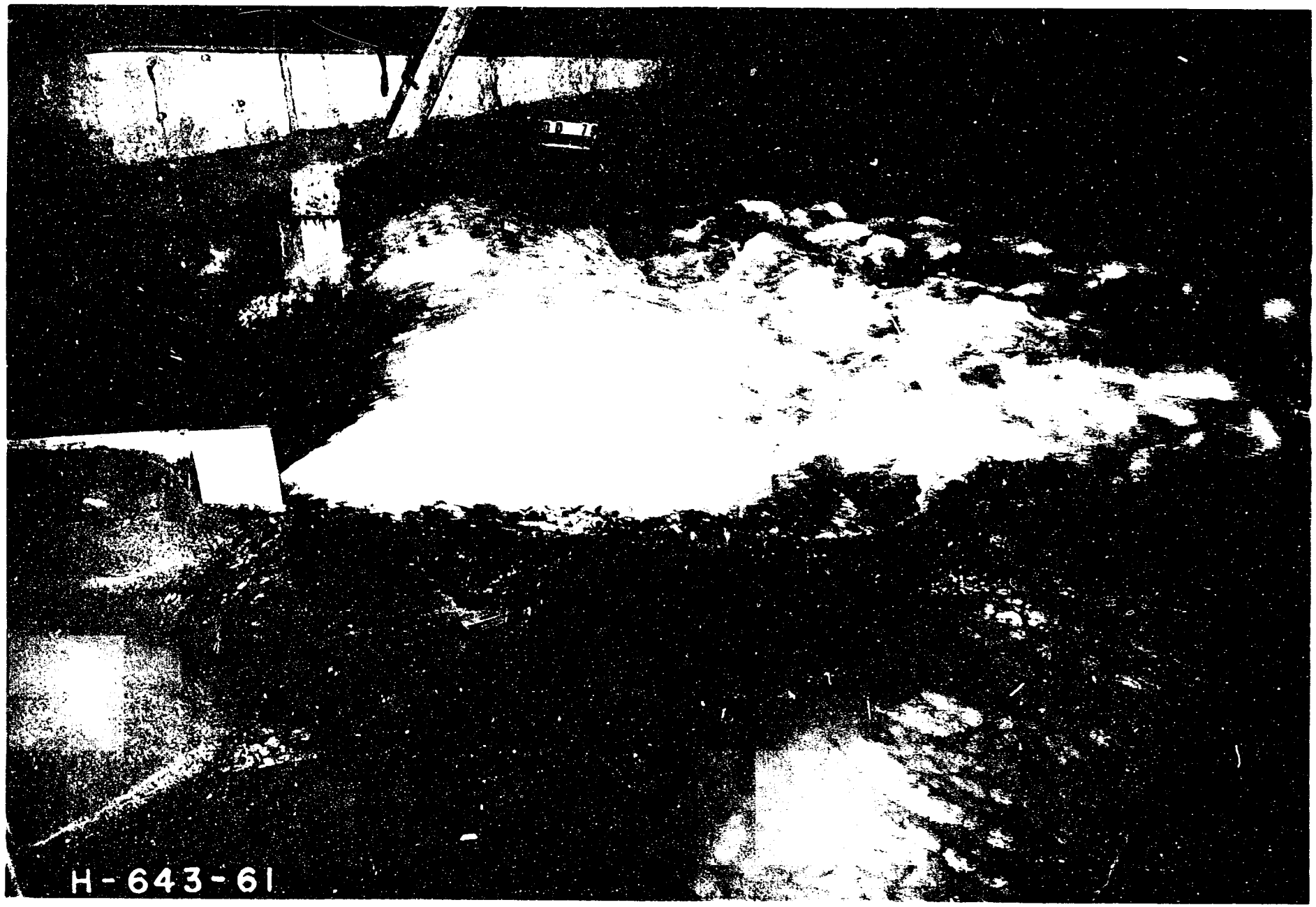

DD 66
H-643-48

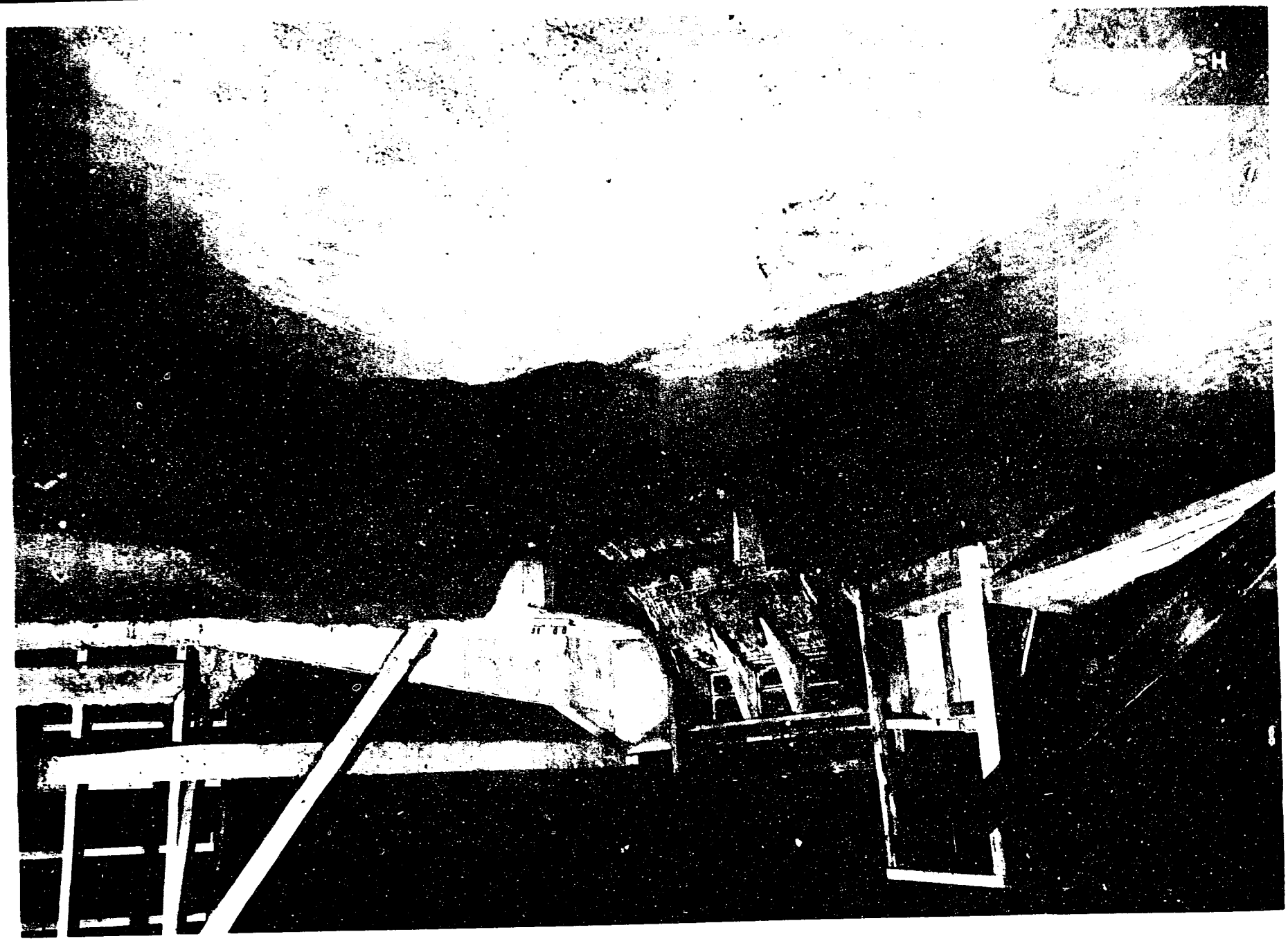

DD 67
H-643-49


DD 10
H-643-52


H-643-53


DD 75


H-643-61




490
490
482
440
490
415