HYDRAULIC MODEL STUDIES FOR THE HOLCOMBE DAM

by

St. Anthony Falls Hydraulic Laboratory
University of Minnesota

Project Report No. 9

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August, 1948
Prepared for the
Northern States Power Company
Minneapolis, Minnesota

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REPORT ON

HYDRAULIC MODEL STUDIES OF HOLCOMBE DAM

FOR

THE NORTHERN STATES POWER COMPANY

Introduction

Hydraulic model studies were made on a 1:43.2 model of the spillway section of the proposed Holcombe Dam to be constructed by the Northern States Power Company on the Chippewa River at Holcombe, Wisconsin. The spillway was designed by the Pioneer Service and Engineering Company of Chicago, Illinois.

The purpose of these tests was to obtain information on the extent of the erosion to be expected below the spillway section and to determine weir coefficients and the pressure distribution on the spillway. Since a rock foundation exists at the dam site, the results of the tests on a model with a movable bed were qualitative, and the measure of a good bucket design was one which directed the erosive force of the jet downstream from the dam and also maintained a covering of bed material against the downstream face of the dam. Modifications in the original design of the bucket section of the spillway were made as directed by the engineering staff of the Pioneer Service and Engineering Company.

Hydraulic Model Studies

Since the force of gravity is the predominant force acting on the model, the other forces such as fluid viscosity, surface tension and the like have been neglected and the model operated in accord with the Froude Model Law. Model requirements in addition to geometric similarity are that the ratios of the velocities in the model and the

prototype vary as the square root of the length ratio. Using a model scale of 1:43.2 the following ratios are thus established.

Quantity	Ratio-Model to Prototype
Lengths	1:43.2
Areas	1:1866
Velocities	1:6.56
Discharges	1:12,300
Pressures	1:43.2

The model was tested with varying headpool and tailwater elevations both with free flow (all gates open) and for various discharges regulated by partial opening of the Taintor gates.

The prototype structure consists of thirteen gate bays, six of which have bucket lips at the same elevation and the remaining seven bays have bucket lips at varying higher elevations. Since the flow in the prototype was two-dimensional, the model tested consisted of a section of the spillway which included one full-gate opening with accompanying piers and two half-gate openings. This choice of model section eliminated the effect of the channel sidewalls which would have been evident if two full gates had been used with one center pier and two half piers.

The model section tested represented two-thirteenths of the total spillway length, and therefore the discharge through the model was assumed to be a like portion of the total flow. Tailwater depths were obtained from a tailwater stage relation curve furnished with the hydraulic plans (see Fig. 2).

Description of Model

The model tests were performed in a glass-walled channel 20 in. wide and 26 in. deep (see Fig. 1). The model was supplied by gravity flow from the Mississippi River and the discharge was measured

by a sharp edged suppressed weir. Measurements of the water surface and bed elevations were made by means of point gages reading to the nearest 0.001 ft or corresponding to about 1/2 inch in the prototype. The pressure on the face of the spillway was measured by piezometers embedded in the model and led through the bottom of the channel to a manometer board. Pressure readings were made to the nearest 0.005 ft or about 2½ inches in the prototype.

The model was constructed of concrete formed to the desired crest shape by casting in a plaster mold. The first tests were made on the all-concrete model, but subsequent revisions after the model was in place in the channel led to the use of a super-strength gypsum cement for the bucket section. This material is readily workable by template to most curved surfaces and is sufficiently non-soluble to withstand short-time usage in the model. Revisions in bucket elevation were made without removing the model from the test channel. The two piers were constructed of wood and the Taintor gates were fabricated of brass.

Test Operations

In a test of a model the channel was flooded to a greater depth than the anticipated tailwater stage; after which the approximate discharge was turned into the channel. Establishment of the proper headpool and tailwater elevations were carried out simultaneously by regulation of the discharge and the tailwater gate. The length of test was fixed by the time required to establish a stabilized erosion pattern below the dam. In all but a few runs, little movement of the bed material was observed after 120 minutes.

Discharge Coefficients

Coefficients of discharge were computed for Runs 6 through 23. The Francis weir formula including correction for pier contractions

was used in computing weir flow coefficients (see Tech. Memo. No. 2). Where rapid erosion occurred in the approach channel, several bed measurements were made of the upstream bed during the period of the test. For the tests in which the flow was controlled by the Taintor gates, the coefficient of discharge was computed from the equation $Q = CA\sqrt{2gh}$, where h is measured distance from the water surface to the bottom of the gate plus the approach velocity head.

Presentation of Test Data

The model data consist of four series of tests. The profile of the downstream face of the dam was the same for all models, with the exception that the bucket was varied in length and elevation. The principal dimensions of the four models are given in Fig. 4, 7, and 29.

The test results are presented in four technical memorandums which were transmitted as progress reports as each series of tests was completed. No further amplification of the test data has been made. A summary of the test data is presented in Table I.

Technical Memorandum No. 1 reports test runs 1 to 3 made on the original model as shown in Fig. 2. Bucket elevation for this model was 989 ft. The approach channel did not represent a movable bed channel.

Technical Memorandum No. 2 (Runs 6 to 10) includes tests on the first revision of the model (see Fig. 3). Model changes were an increase in the bucket elevation from 989 to 991 ft and a lengthening of the bucket apron of approximately 7 ft. A movable bed was also added to the approach channel.

Technical Memorandum No. 3 (Runs 16 to 23) covers information on the third revision of the test model with the bucket elevation at 985 ft and the apron extended a distance of approximately 4 ft farther downstream than revision no. 1 (see Fig. 5).

Technical Memorandum No. 4 reports the test data from the second revision of the model in which the bucket was raised to an elevation of 1010 ft (see Fig. 4).

TABLE 1

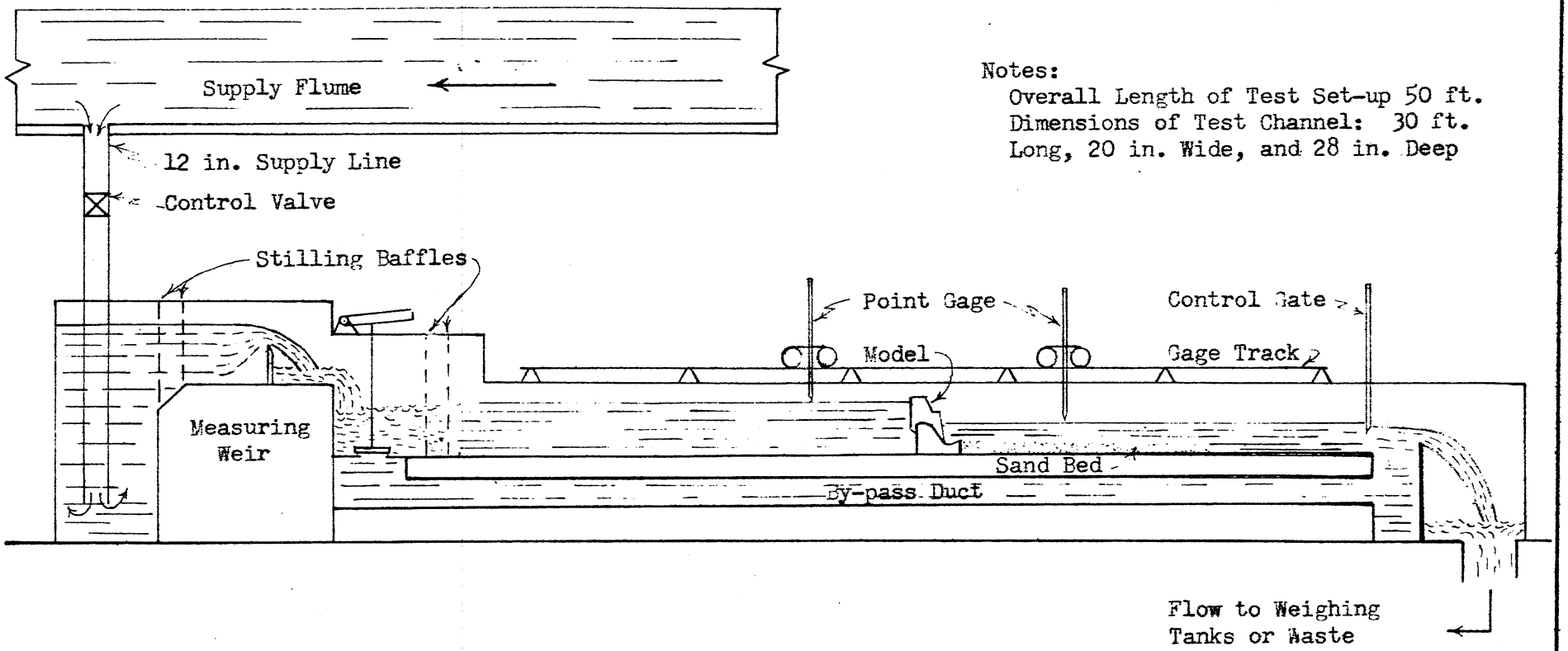
HOLCOMBE DAM

TEST DATA SUMMARY

Run	Date		Discharge c.f.s	Headwater Elev. ft	Tailwater Elev. ft	Vel. of Approach ft/sec	Head on Weir ft	Effective length of Weir ft	Elev. of Bucket ft	Angle of Apron degrees	Coefficient of Discharge*
1	4-22		216,000	1050	1034.5				989	27	
2	4-22		164,000	1045	1028				989	27	
3	4-22		216,000	1050	1034.5				989	Horiz.	
4	4-30		216,000	1050	1034.5				989	Horiz.	
5	4-30		202,000	1050	1034				989	Horiz.	
6	5-14		165,000	1045	1028	1.64	22	57.2	991	27	3.91
7	5-20		100,000	1045	1018.5	1.05	16	Orifice	991	27	0.647
8	5-20		216,000	1050	1034.5	1.47	27	56.5	991	27	3.85
9	5-28		10,800	1045	1003	0.58	22	28.6	991	27	3.54
10	6-1		10,800	1045	1003	0.59	22	28.6	991	Horiz.	3.57
11	6-15		140,000	1045	1028	1.60	22	57.2	1010	27	3.39
12	6-15		187,500	1050	1034.5	1.65	27	56.6	1010	27	3.37
13	6-16		100,000	1045	1018.5	1.06	16.1	Orifice	1010	27	0.637
14	6-17		11,200	1045	1010	.54	22	28.6	1010	27	3.68
15	6-17		11,200	1045	1012	0.56	22	28.6	1010	27	3.66
16	6-21		11,200	1045	1002.5	0.56	22	28.6	985	20	3.70
17	6-21		50,000	1045	1011	0.24	19.35	Orifice	985	20	.676
18	6-22		165,000	1045	1028	1.73	22	57.1	985	20	3.92
19	6-22		216,000	1050	1034.5	1.53	27	56.5	985	20	3.82
20	6-23		11,200	1045	1002.5	.55	22	28.6	985	27	3.72
21	6-24		50,000	1045	1011	0.24	19.35	Orifice	985	27	.676
22	6-24		165,000	1045	1028	1.73	22	57.1	985	27	3.86
23	6-25		216,000	1050	1034.5	1.76	27	56.5	985	27	3.76

* These values are average readings after approach channel bed was stabilized.

FIGURE 1
EXPERIMENTAL TEST CHANNEL
USED IN MODEL TESTS
Model Scale 1:43.2



Notes:
Overall Length of Test Set-up 50 ft.
Dimensions of Test Channel: 30 ft. Long, 20 in. Wide, and 28 in. Deep

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Minneapolis, Minn. May, 1948

Fig. 1

APPROXIMATE TAIL WATER STAGE RELATION CURVE

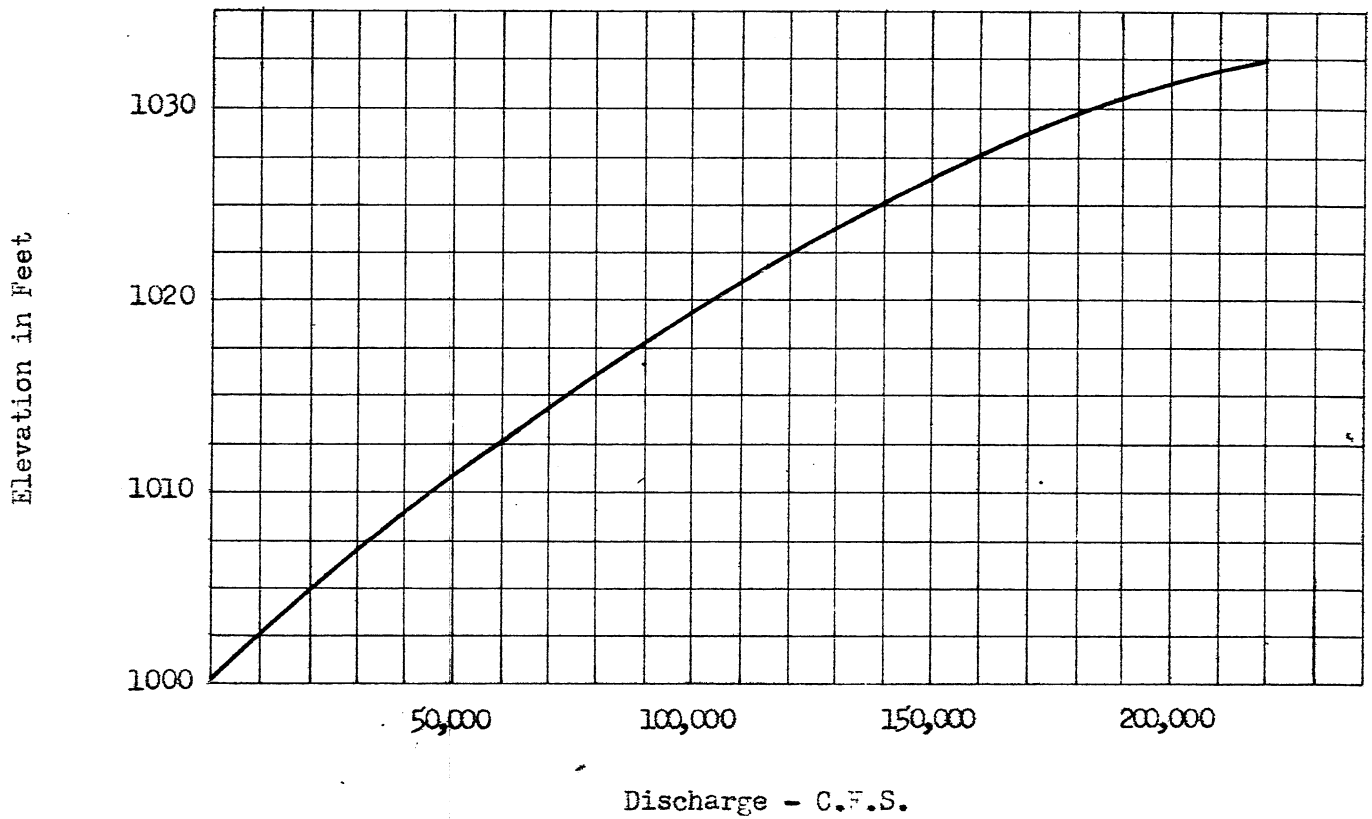

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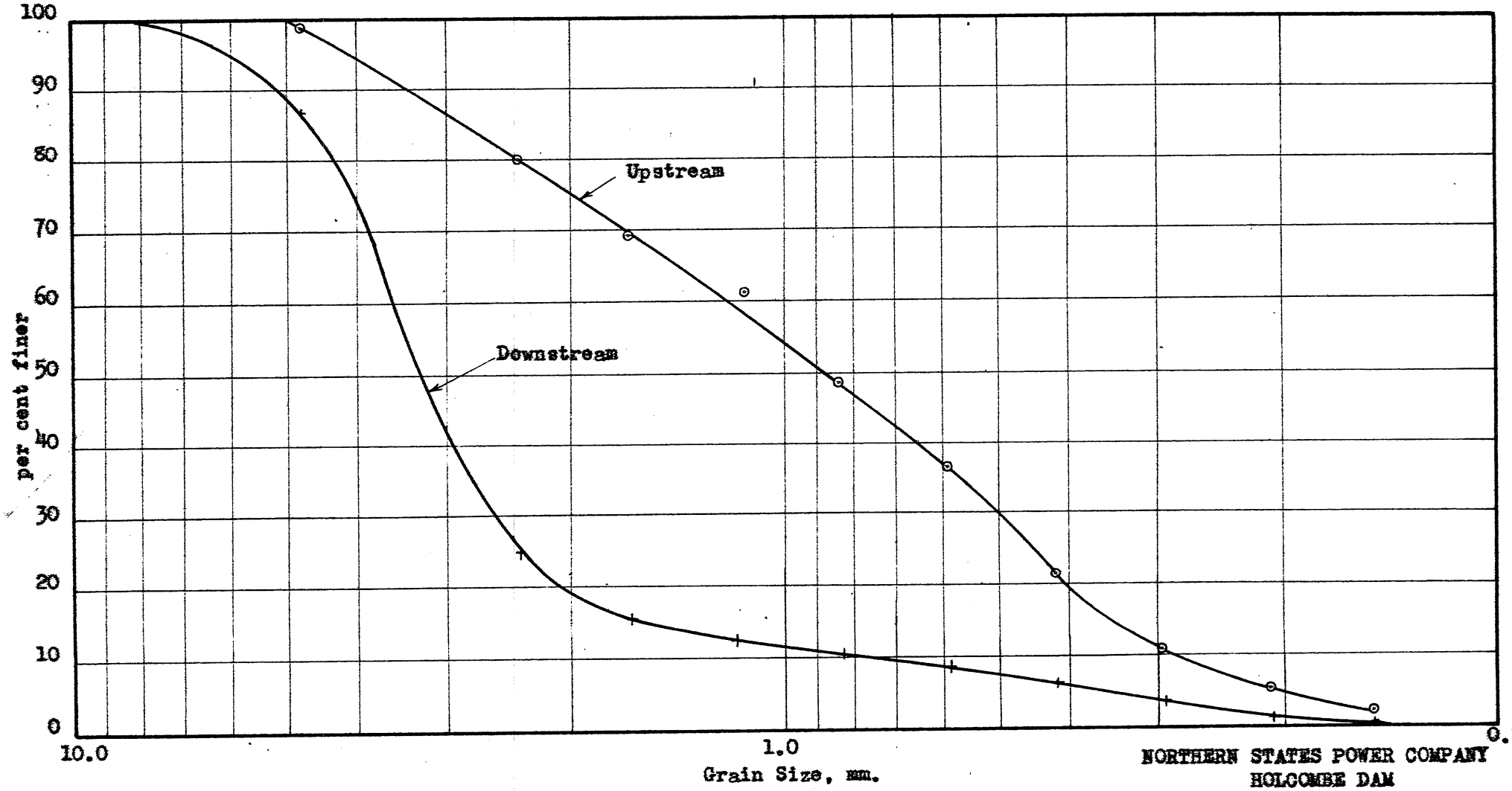
Fig. 2



Sieve Analysis of Bed Material

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 10, 1948

Fig. 3

HYDRAULIC MODEL STUDIES OF HOLCOMBE DAM

as conducted for

THE NORTHERN STATES POWER COMPANY

by

THE ST. ANTHONY FALLS HYDRAULIC LABORATORY

Technical Memorandum No. 1

The following data represent the results of three test runs on the spillway section of the dam.

Runs No. 1 and No. 2 were made on the original model (see Fig. 4) as requested, and Run No. 3 represents a modified form.

Run No. 1

For the given pool elevation of 1050 ft, the discharge through the structure was found to be 33,800 cu ft per sec for the model section of two gate widths. Assuming uniform discharge through each of the 13 gates in the dam, the total flow through the dam is 216,000 cu ft per sec. The tailwater stage relation curve gave a tailwater elevation of 1034.5 ft for a discharge of 216,000 cu ft per sec.

Both water surface and piezometer measurements were recorded for this flow and are presented in Fig. 5.

The material in the movable bed consisted of coarse sand passing a No. 3 mesh plus approximately 10 per cent of 1½ in. gravel. This material was rapidly scoured down to the steel floor of the flume bottom and became stabilized as shown in Fig. 1. No further movement of the material was evident although the run lasted approximately one hour.

The data from the piezometers show that the pressure on the face of the spillway is positive for all points measured, and there is no evidence

of separation of the nappe from the spillway.

Run No. 2

The discharge for a pool elevation of 1045 ft was found to be 164,000 cu ft per sec for the whole dam with a corresponding tailwater elevation of 1028 ft. The spillway pressures for this flow are all positive.

Scour for this run was similar to Run No. 1 except that the scour hole was shorter than for Run No. 1.

Water surface and piezometer data are given in Fig. 5.

Run No. 3

Run No. 3 was made to explore the possibility of improving the flow directly below the spillway and to reduce the amount of scour of the bed material.

As a starting point, a portion of the spillway, shown by dashed lines on the drawing of the spillway section, was removed and an apron with a horizontal floor 30 ft in length was added. A sill 3 ft wide and 5 ft high was placed at the end of this apron extension.

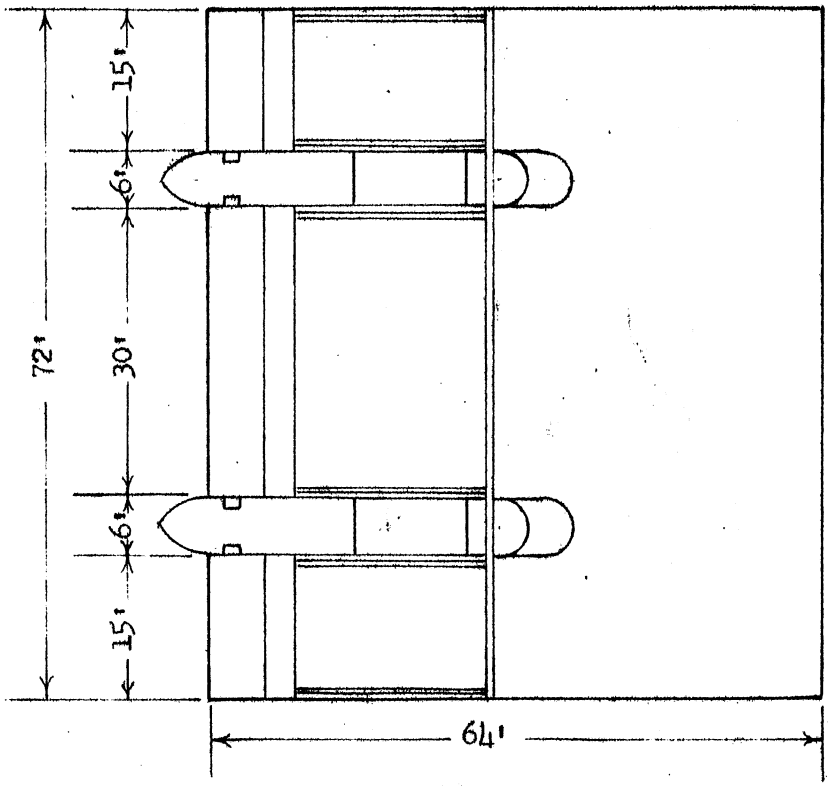
When the model was operated with a pool elevation of 1050 ft and tailwater elevation of 1034.5 ft, the flow below the spillway was greatly improved. The bed material was not scoured as deep as for Runs 1 and 2 and the scour line was established before the scour hole reached the bottom of the flume.

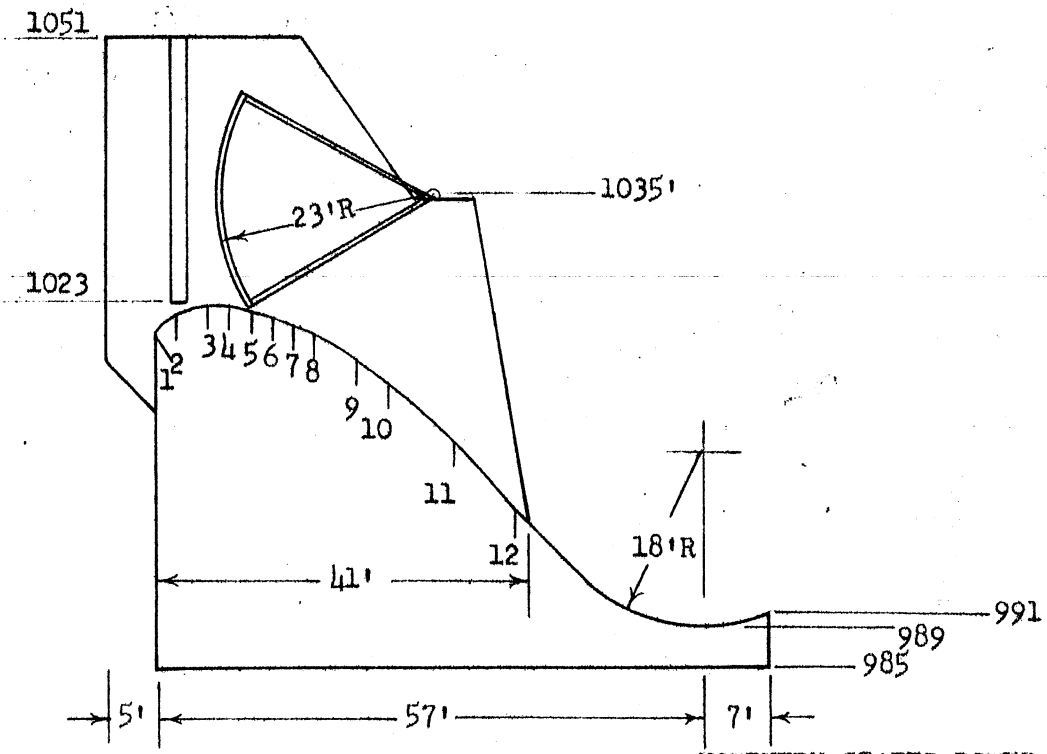
As in the other two runs, the pressure on the spillway was positive for all points measured. The water surface and pressure measurements are shown in Fig. 6.

The tests indicate that further improvements in the flow conditions below the spillway might be obtained by varying the length and elevation

of the apron, by alterations in the shape and dimensions of the end sill, by the addition of baffle piers, or by a combination of these elements.

The model studies were conducted and summarized by Mr. Sigurd N. Anderson of the Laboratory staff.





Bucket Design - Original Model

NORTHERN STATES POWER CO.
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydr. Lab.
Minneapolis, Minn. May, 1948

Fig. 4

NORTHERN STATES POWER COMPANY

HOLCOMBE DAM

HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory

Minneapolis, Minn. April, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 1	Run 2
1	1020.2	1038.7	1037.4
2	1022.3	1024.7	1026.8
3	1023.0	1024.0	1026.0
4	1022.9	1024.0	1025.3
5	1022.5	1024.7	1024.9
6	1021.9	1024.9	1024.5
7	1021.1	1024.9	1023.8
8	1020.2	1024.7	1022.7
9	1017.5	1025.3	1022.3
10	1015.1	1027.9	1021.9
11	1009.1	1032.9	1023.2
12	1001.5	1037.0	1029.7

SPILLWAY SECTION EXPERIMENTS

Scale of Model 1:43.2

Drawing Scale: As indicated

Run	1	2
Q_m	2.70	2.05
Q_p	216,000	164,000
Pool Elev.	1050'	1045'
Tailwater Elev.	1034.5'	1028'

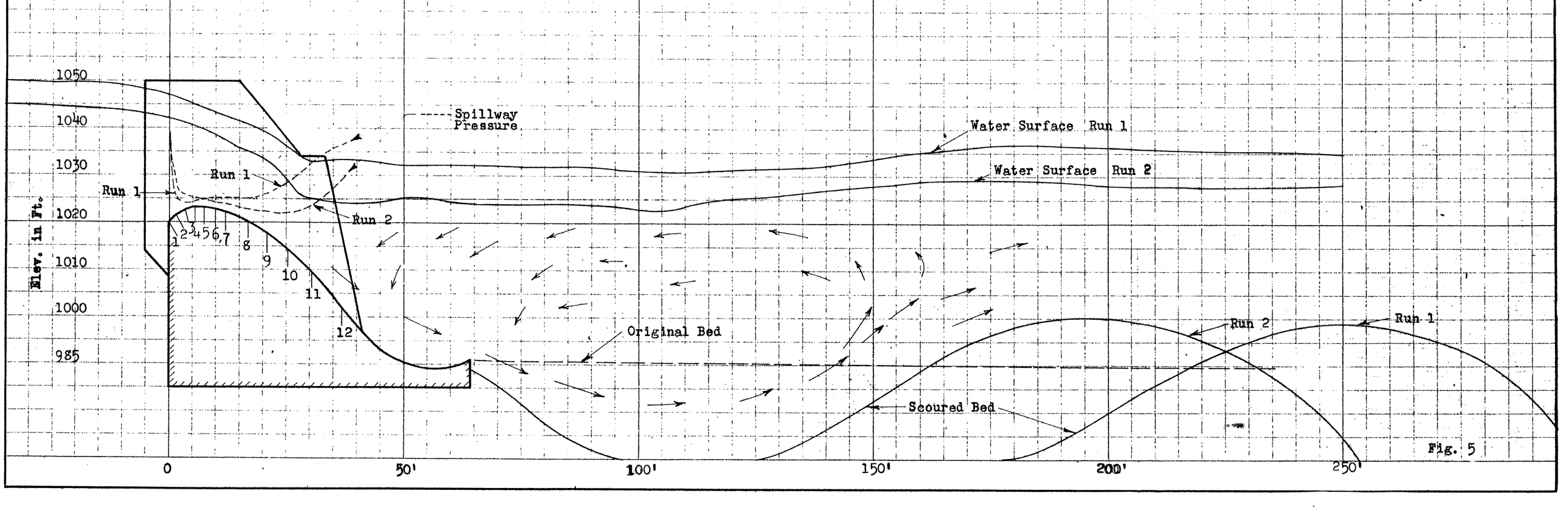


Fig. 5

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM

HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. April 28, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 3
1	1020.2	1038.8
2	1022.3	1024.7
3	1023.0	1023.6
4	1022.9	1023.6
5	1022.5	1023.2
6	1021.9	1023.2
7	1021.1	1023.0
8	1020.2	1022.3
9	1017.5	1022.7
10	1015.1	1023.6
11	1009.1	1028.3
12	1001.5	1034.8

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale:	As indicated
Run	3
Q_m	2.70 cfs
Q_p	216,000 cfs
Pool Elev.	1050'
Tailwater Elev.	1034.5'

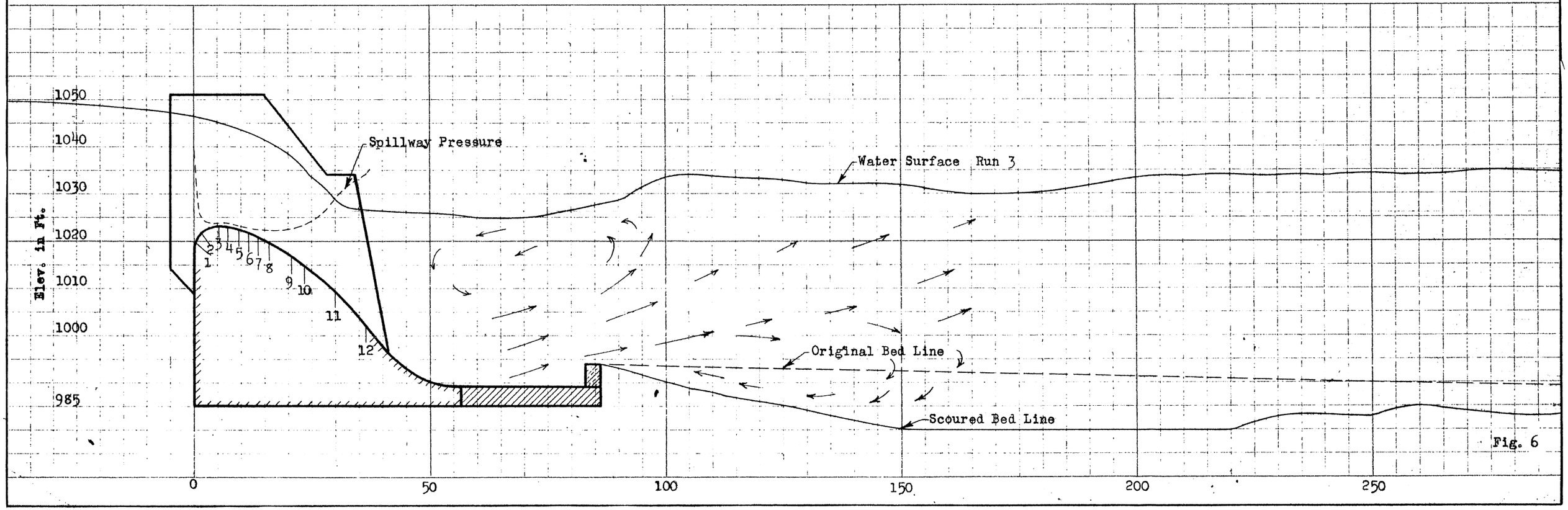


Fig. 6

HYDRAULIC MODEL STUDIES OF HOLCOMBE DAM

as conducted for

THE NORTHERN STATES POWER COMPANY

by

THE ST. ANTHONY FALLS HYDRAULIC LABORATORY

Technical Memorandum No. 2

In accordance with instructions from Mr. Hill, the model was rebuilt as shown in the sketch "Bucket Design - First Revision" (see Fig. 7). A sand bed was placed in the approach channel to the elevation 1020 ft and for a distance of 220 ft upstream from the dam. (For grain size analysis, see Fig. 3).

Runs 4 and 5 were made to investigate the effect of various baffle piers and were done before Mr. Wehner's letter of May 10, 1948, was received. Since no additional information in this direction was desired, the data from Runs 4 and 5 are not presented in this summary. To obtain the desired flow conditions the model was equipped with a set of Taintor gates which consisted of one full gate and two half gates.

Run No. 6

With a head pool elevation of 1045 ft, the unrestricted flow through the model was found to be 165,000 cu ft per sec. The required tailwater elevation for this flow was 1028 ft.

The erosion of the sand bed in the approach channel was very rapid at the start of the test, and the rate of scour decreased until a stable profile was reached after a run of 110 minutes (see Fig. 8).

Using the Francis weir formula,*

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*Engineering for Dams, Hinds, Creager, Justin, pp. 364-366

$$Q = Cl_n \left[(h_v + h_o)^{1.5} - h_v^{1.5}\right] \text{ where}$$

C = Coefficient of discharge
l_t = Actual crest length
l_n = Effective length of crest
n = The number of end contractions
k = Contraction coefficient
h_o = Head on crest
h_v = Velocity head in approach channel

and $l_n = l_t - (h_v + h_o)\,nk$
k for the model pier = 0.03
n = 4 (for 2 piers—one full gate and two half gates)
$l_n = l_t - 0.12\,(h_v + h_o)$

The coefficient of discharge "C" varied as follows during the period of the test.

Time	Q_o	h_v	h_o	l_n	C
minutes	c.f.s.	ft	ft	ft	
0	174,000	3.51	22	56.9	3.89
8	172,000	2.16	22	57.1	3.90
18	169,000	2.12	22	57.1	3.94
25	168,000	1.95	22	57.1	3.92
55	166,500	1.91	22	57.1	3.92
110	164,000	1.64	22	57.2	3.91

The variation of "C" for Run No. 6 is within the range of the experimental error and can be considered to have a constant value for the range of approach velocities encountered during the test.

The scour conditions for this test were greatly improved over Run No. 2, which had the same test conditions with the exception that the bucket elevation was raised from 989 ft to 991 ft and the sloping apron lengthened 7 ft. At the end of the test period, the bed below the dam had reached a stable grade and only slight movement was taking place (see Fig. 9).

The changes made in the bucket design not only shifted the scour hole approximately 100 ft downstream, but also caused bed material to be constantly carried back to the toe of the dam. The depth of scour at the end of the test was considerably less than for Run No. 2.

Run No. 7

To maintain an elevation of 1045 ft with a discharge of 100,000 cu ft per sec, it was necessary to close the Taintor gates on the spillway to an elevation of 1035 ft at the bottom of the gate. Erosion in the approach channel averaged 3 ft in depth but the increase in cross-sectional area did not affect the discharge coefficient. The upstream channel reached a stable grade early in the test. Duration of test was 90 minutes (see Fig. 10).

Using the basic orifice flow formula $Q = CA\sqrt{2gh}$

where $h = h_o + h_v$

and h_o = head on center of gate opening
h_v = velocity head in approach channel
C = coefficient of discharge

for Q = 15,350 cu ft per sec (discharge through 2 gates)
A = 60 x 12 = 720 sq ft
h_v = 1.05 ft
h_o = 16 ft

then C = 0.647

Note: velocity of approach measured at 0 + 60 ft upstream from dam.

The downstream bed profile as shown in the drawing of test 7 (see Fig. 11) is the elevation of the center line. Sufficient bed material was carried back by return flow to keep the toe wall covered to an elevation of 996 ft.

Run No. 8

This test was made with a flow of 216,000 cu ft per sec and a pool elevation of 1050 ft. The upstream approach channel was rapidly eroded after

the start of the test. Most of the scour occurred during the first half of the test (see Fig. 12). Considerable drawdown occurred above the dam and the head measuring point was moved from 80 ft to 200 ft above the dam. The velocity of approach was computed for the cross-section at 200 ft above the dam. The erosion of the bed material below the dam was similar to Run No. 7, except that the scour hole was deeper and further downstream from the toe of the dam (see Fig. 13).

Computation of accurate values of the discharge coefficient for the beginning period of the run was difficult because the bed in the approach channel was eroding rapidly and the headwater and tailwater elevations were constantly changing. However, after about 30 minutes, the rate of scour was less and the observations were made with greater accuracy.

Coefficients of discharge for three periods during the test are:

Time	Q_p	h_v	h_c	l_n	C
minutes	c.f.s.	ft	ft	ft	
12	220,000	1.68	27	56.5	3.87
45	220,000	1.69	27	56.5	3.91
100	216,000	1.47	27	56.5	3.85

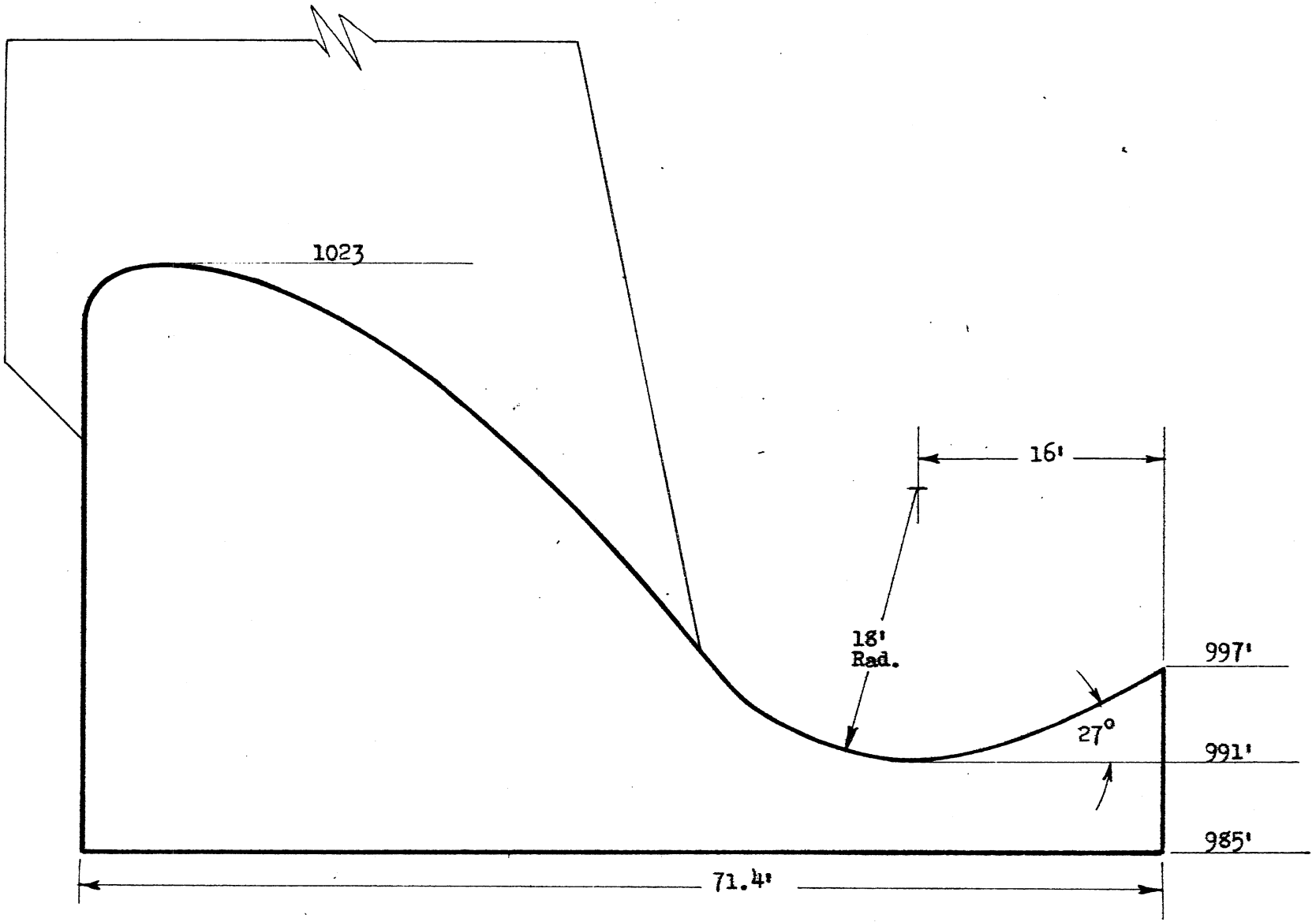
Run No. 9

This test was made with center gate of the model fully open. The two half gates were closed and sealed. Very little movement of the bed material in the approach channel was observed. Scour occurred only for a distance of 40 ft upstream of the dam. In comparison to the previous runs, the erosion of the bed material below the toe of the dam was very severe (see Fig. 14). However, this was, no doubt, due to the low tailwater rather than to the bucket design. The erosion uncovered the steel floor of the channel at several points. The coefficient of discharge

for this run was found to be "C" = 3.54. Duration of test was 100 minutes.

Run No. 10

Operating conditions for this run were identical with Run No. 9, with the exception that the inclined portion of the bucket was removed above the elevation of 991 ft. Erosion of the downstream bed was similar to Run No. 9, but did not reach as great a depth (see Fig. 15). The coefficient of discharge for one gate open was "C" = 3.57. Considering the height of the bed at the start of the test, the erosion for this run was less severe than for Run No. 9.



Bucket Design - First Revision

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 8, 1948

Fig. 7

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM

HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 8, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	6
Q_m	2.06 cfs
Q_p	165,000 cfs
Pool Elev.	1045'
Tailwater Elev.	1028'
Bucket Elev.	991'
Apron	27°

APPROACH CHANNEL SCOUR TEST

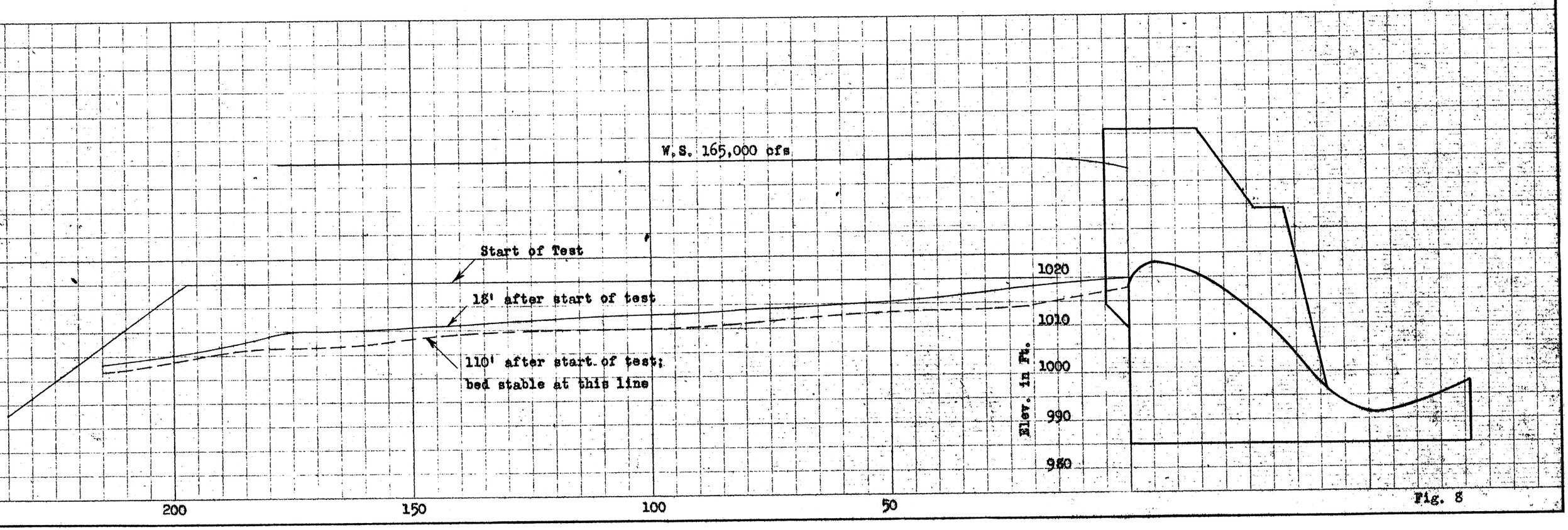


Fig. 8

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 7, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 6
1	1020.2	1043.8
2	1022.3	31.8
3	1023.0	1028.0
4	1022.9	1026.2
5	1022.5	1024.9
6	1021.9	1024.7
7	1021.1	1023.9
8	1020.2	1022.1
9	1017.5	1022.1
10	1015.1	1021.7
11	1009.1	1025.6
12	1001.5	1032.7

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
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Run 6	
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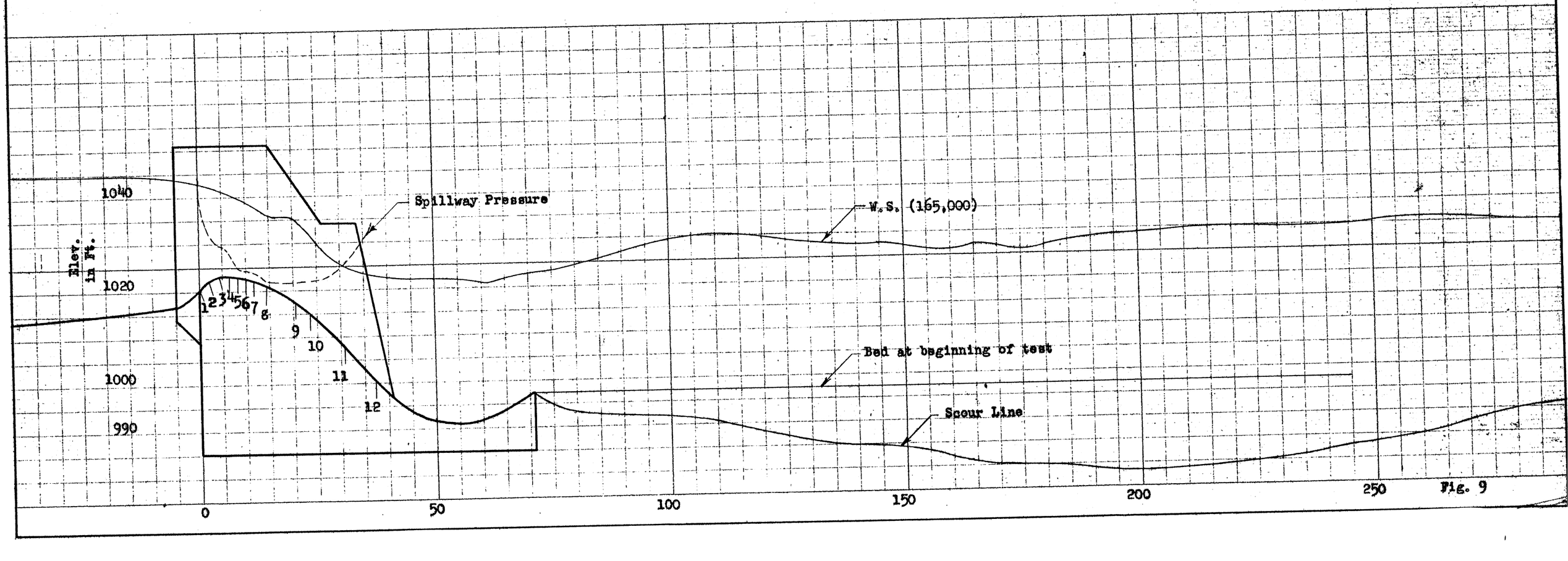


Fig. 9

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM

HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 7, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	7
Q_m	1.25 cfs
Q_p	100,000 cfs
Pool Elev.	1045'
Tailwater Elev.	1018.5'
Gate Setting	1035'
Bucket Elev.	991'
Apron	27°

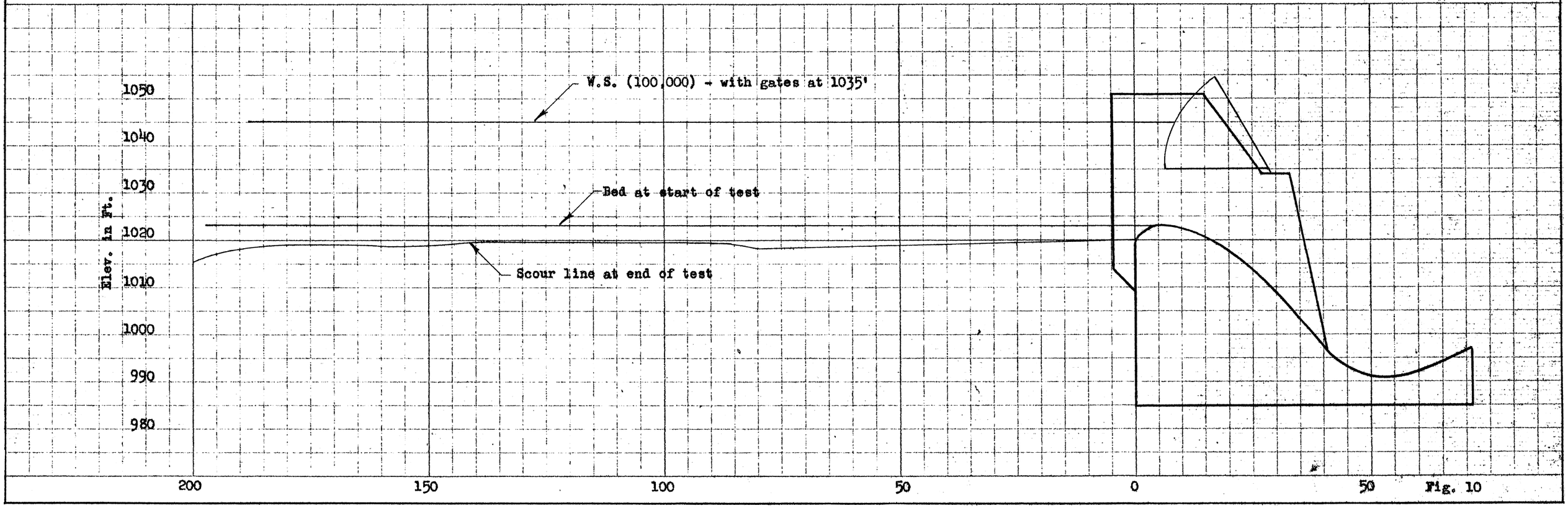


Fig. 10

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 8, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 7
1	1020.2	1045.6
2	1022.3	1039.2
3	1023.0	1032.3
4	1022.9	1028.4
5	1022.5	1025.2
6	1021.9	1023.4
7	1021.1	1021.7
8	1020.2	1019.5
9	1017.5	1019.1
10	1015.1	1015.5
11	1009.1	1010.0
12	1001.5	1012.8

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	7
Q_m	1.25 cfs
Q_p	100,000 cfs
Pool Elev.	1045'
Tailwater Elev.	1018.5'
Gate Setting	1035'
Bucket Elev.	991'
Apron	27°

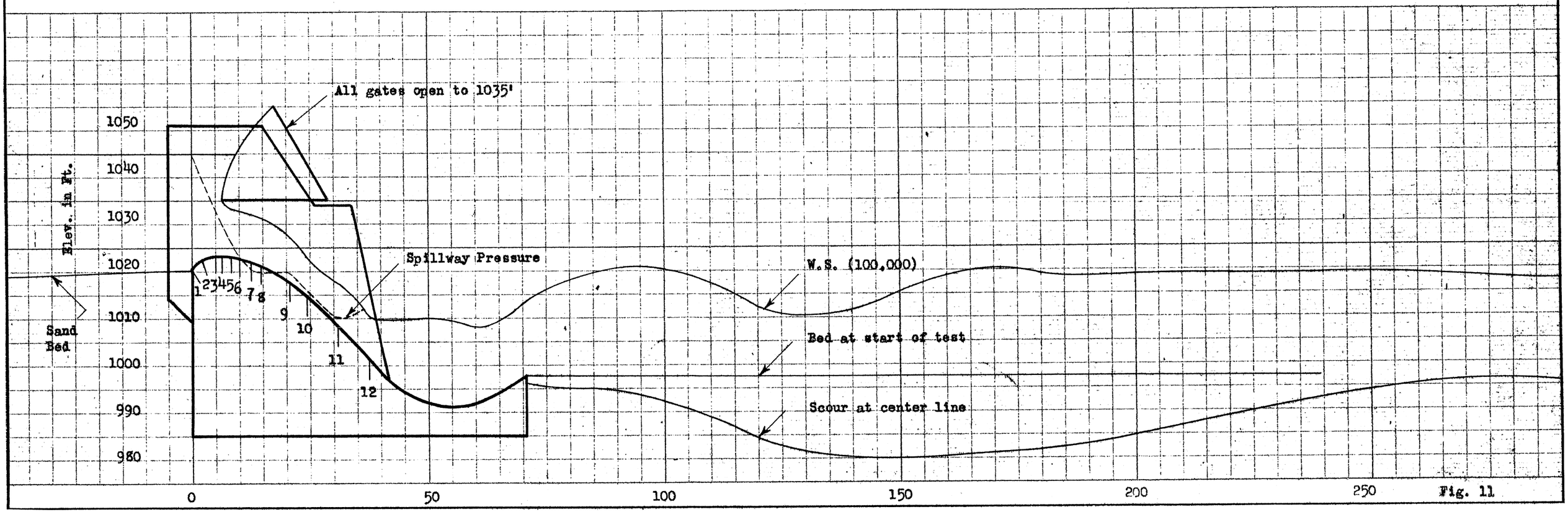


Fig. 11

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 8, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	8
Q_m	2.70
Q_p	216,000 cfs
Pool Elev.	1050'
Tailwater	1034.5
Bucket Elev.	991'
Apron	27°

APPROACH CHANNEL SCOUR TEST

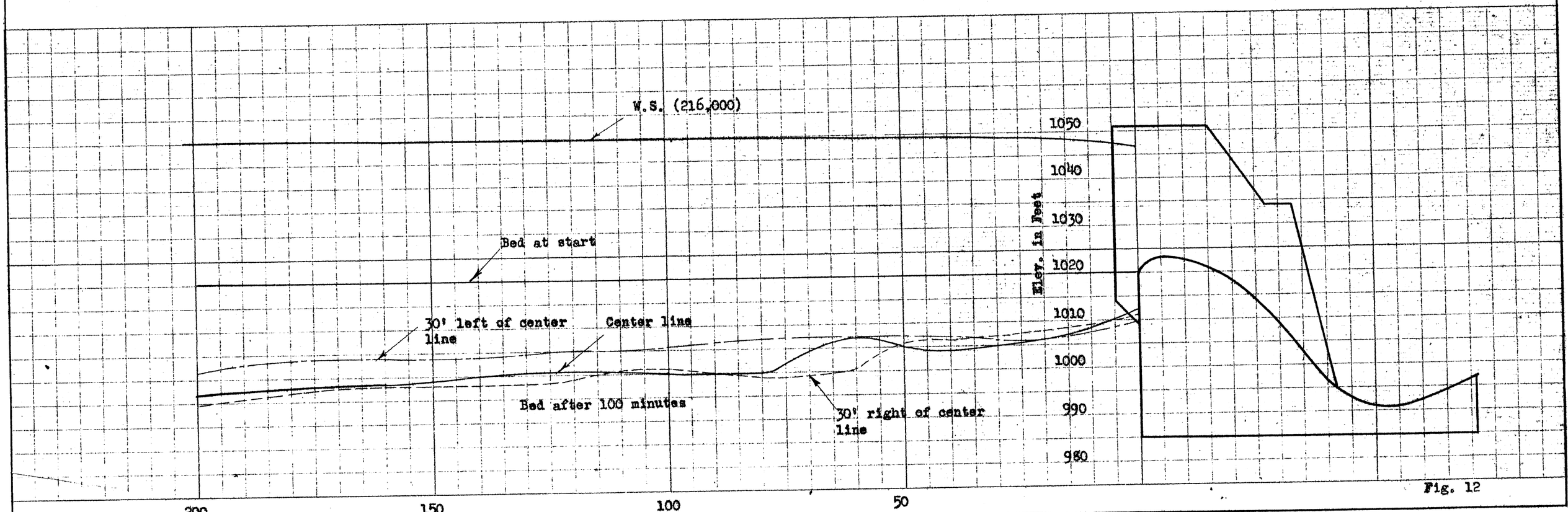


Fig. 12

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 7, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 8
1	1020.2	1047.6
2	1022.3	1036.1
3	1023.0	1024.9
4	1022.9	1023.4
5	1022.5	1022.6
6	1021.9	1022.6
7	1021.1	1022.4
8	1020.2	1021.1
9	1017.5	1021.7
10	1015.1	1022.8
11	1009.1	1029.0
12	1001.5	1042.5

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	8
Q_m	2.70 cfs
Q_p	216,000 cfs
Pool Elev.	1050'
Tailwater	1034.5'
Gate Setting	All gates fully open
Bucket Elev.	991'
Apron	27°

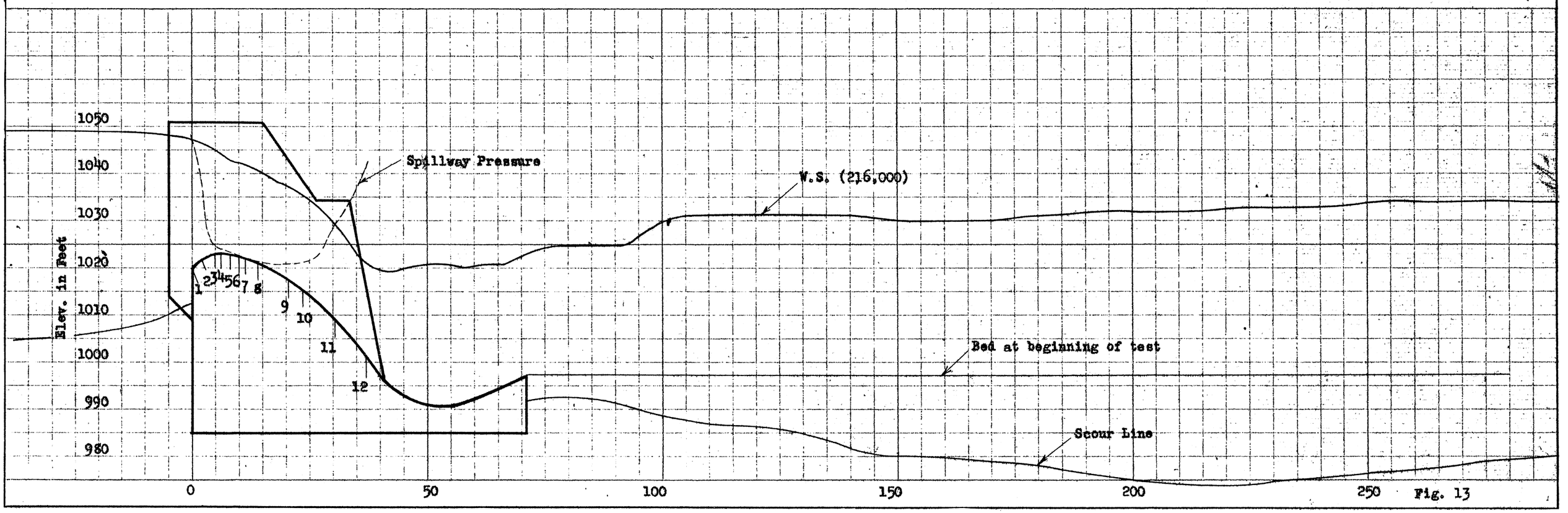


Fig. 13

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM

HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 7, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 9
1	1020.2	1042.6
2	1022.3	1031.2
3	1023.0	1028.0
4	1022.9	1026.7
5	1022.5	1025.2
6	1021.9	1024.0
7	1021.1	1023.2
8	1020.2	1021.1
9	1017.5	1020.4
10	1015.1	1016.5
11	1009.1	1011.0
12	1001.5	1006.2

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	9
Q_m	0.880 cfs
Q_p	10,600 cfs
Pool Elev.	1045'
Tailwater Elev.	1003'
Gate Setting	Center gate fully open
Bucket Elev.	991'
Apron	27°

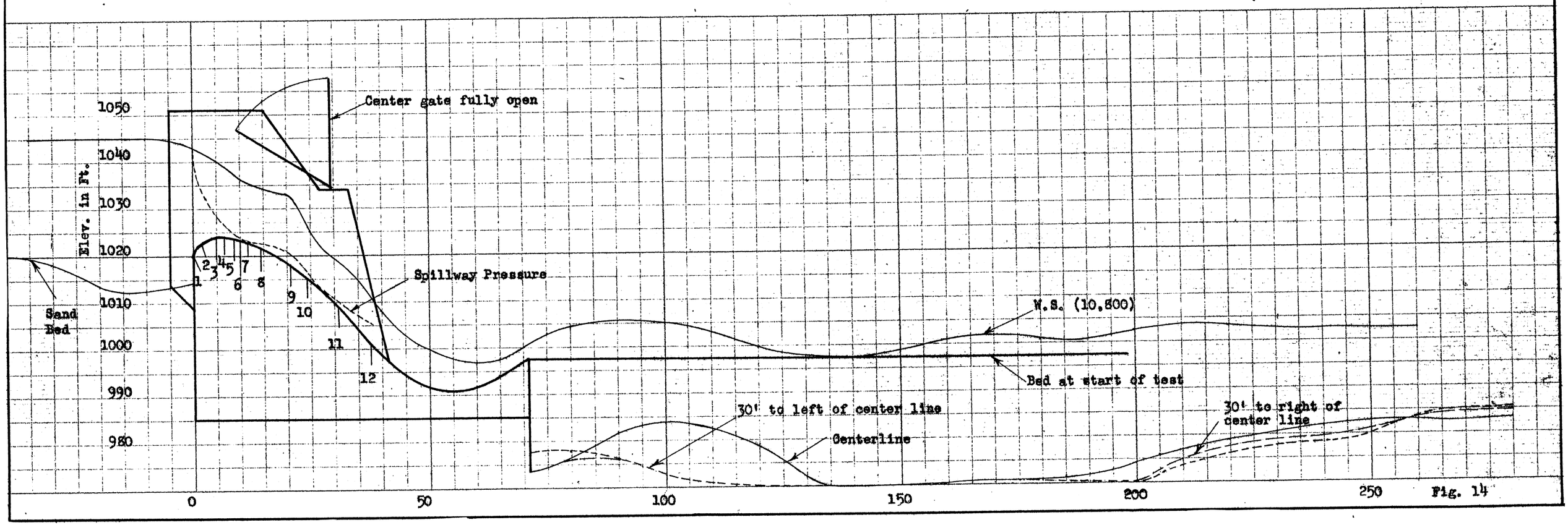


Fig. 14

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM

HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 7, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run
1	1020.2	1042.6
2	1022.3	1031.2
3	1023.0	1028.0
4	1022.9	1026.7
5	1022.5	1025.2
6	1021.9	1024.0
7	1021.1	1023.2
8	1020.2	1021.1
9	1017.5	1020.4
10	1015.1	1016.5
11	1009.1	1011.0
12	1001.5	1006.2

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	10
Q_m	0.885 cfs
Q_p	10,900 cfs
Pool Elev.	1045'
Tailwater Elev.	1003'
Bucket Elev.	991'
Apron	Horizontal

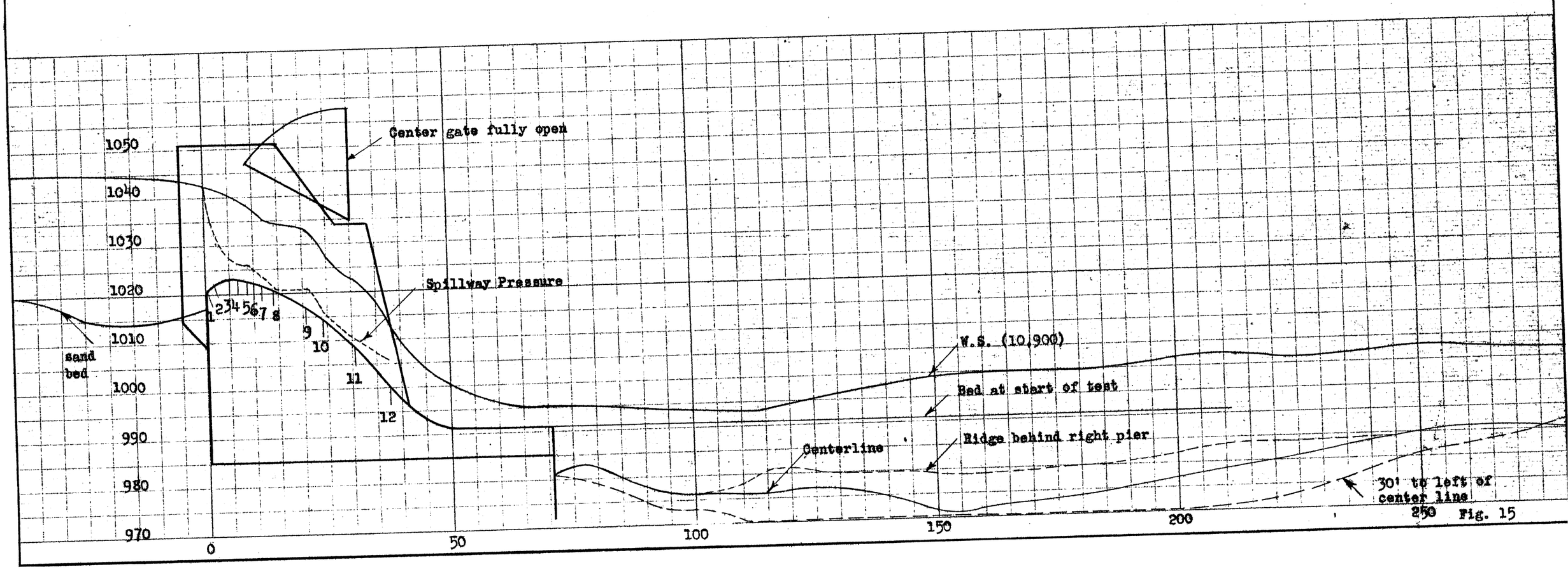


Fig. 15

HYDRAULIC MODEL STUDIES OF HOLCOMBE DAM

as conducted for

THE NORTHERN STATES POWER COMPANY

by

THE ST. ANTHONY FALLS HYDRAULIC LABORATORY

Technical Memorandum No. 3

These additional tests were run on the model as requested by Mr. Wehmer in his letter of June 17, 1948, to Mr. Hibbert Hill. The model was rebuilt using the previous profile, lowering the bucket to an elevation of 985 ft, and extending the apron to 76 ft from the face of the dam (see Fig. 16).

Four tests (Runs 16 to 19) were made with an apron slope of 20° and an elevation at the top of the slope of 989.7 ft. In addition, a series of four runs (Runs 20 to 23) were made with the same bucket elevation, with the exception that the apron slope was changed to 27°, which brought the top of the apron to an elevation of 991.0 ft.

Attention is directed to the discharges obtained for test Runs 16, 18, 20, and 22. The discharges for these tests vary slightly from those requested and they were obtained by bringing the pool to an elevation of 1045 ft.

Information on Runs 11 to 15 is not included in this report because work on these runs was temporarily suspended, giving preference to Runs 16 to 23, as was requested by Mr. Wehmer.

Run No. 16

With a headpool elevation of 1045 ft and the center gate fully open, the discharge through the model was 11,200 cu ft per sec. The coefficient

of discharge for this test was C = 3.72. The depth and length of the scour hole below the apron were considerably smaller than for either Runs 9 or 10. Also, the bed material was carried back against the toe wall by return flow from the jet. No erosion occurred in the upstream channel except in the immediate vicinity of the crest (see Fig. 17).

Run No. 17

To obtain a flow of 50,000 cu ft per sec with a headpool elevation of 1045 ft, the spillway gates were lowered to an elevation of 1028.3 ft (at the bottom of the gate). No erosion was evident in the upstream approach channel. The flow pattern below the dam was the best observed for any of the test runs made so far (see Fig. 18). No movement of the bed material was observed below the station 2 + 00. Tailwater for this run was at elevation 1011 ft. The coefficient of orifice discharge for this test is C = 0.676.

Run No. 18

Flow through the model with all gates fully open and a pool elevation of 1045 ft was 165,000 cu ft per sec. Tailwater elevation for this run was 1028 ft. The depth of the scour hole for this test was 4 ft less than for the similar test with the bucket elevation at 991 ft (Run No. 6, see Fig. 19).

The coefficient of discharge varied as follows during the test. The section used for determining the approach velocity was located at 100 ft above the dam.

Time	Q_p	h_v	h_c	l_h	C
minutes	c.f.s.	ft	ft	ft	
0	25,400	3.09	22	57.9	3.71
15	25,400	2.22	22	57.1	3.83
25	25,400	2.02	22	57.1	3.88
60	25,400	1.68	22	57.1	3.91
120	25,000	1.73	22	57.1	3.92

Little movement of bed material in the approach channel was observed after 60 minutes. Length of the test was 120 minutes (see Fig. 20).

Run No. 19

With gates fully open and headpool elevation at 1050 ft, flow through the model was 216,000 cu ft per sec. Due to the drawdown in the approach channel, the head measuring station was located at 200 ft above the dam (see Fig. 21). The bed material below the dam was removed to the floor of the channel and after 30 minutes all material was removed to a distance of 300 ft below the dam and the force of the jet was carried below this point (see Fig. 22).

The coefficient of discharge during the test was as follows:

Time	Q_p	h_v	h_c	l_h	C
minutes	c.f.s.	ft	ft	ft	
0	34,400	4.89	27	55.5	3.81
10	33,200	1.63	27	56.5	3.70
30	33,200	1.53	27	56.5	3.62

Run No. 20

Conditions for this test were similar to Run 16. Headpool elevation was 1045 ft, the center gate was fully open, and model discharge was 11,200 cu ft per sec. The coefficient discharge for this flow was C = 3.72. The depth of erosion and length of the scour hole were approximately the

same as for Run No. 16. The only noticeable difference between the 20° and the 27° apron is that the toe of the dam was covered more completely for the 20° apron than for the 27° apron (see Fig. 23).

Run No. 21

Flow for this test was regulated by the gate, as in Run No. 17. Elevation at the bottom of the gate was 1028.3 ft. The coefficient of orifice discharge for this test was C = 0.676. Erosion below the dam was nearly the same as for Run No. 17 (see Fig. 24). No erosion occurred in the approach channel. Tailwater elevation was 1011 ft.

Run No. 22

Discharge with the headpool at 1045 ft, with all gates open, was 165,000 cu ft per sec. Tailwater elevation was 1026 ft. The depth of scour below the dam was slightly greater for this run than for Run No. 18 (See Fig. 26).

The coefficient of discharge for this run varied as follows. The head measuring station was located at 100 ft upstream from the dam.

Time	Q_p	h_v	h_o	l_n	C
minutes	c.f.s.	ft	ft	ft	
10	24,600	2.14	22	57.1	3.72
30	25,200	2.11	22	57.1	3.82
45	25,200	1.99	22	57.1	3.83
75	25,400	2.03	22	57.1	3.83
120	25,400	1.73	22	57.1	3.86

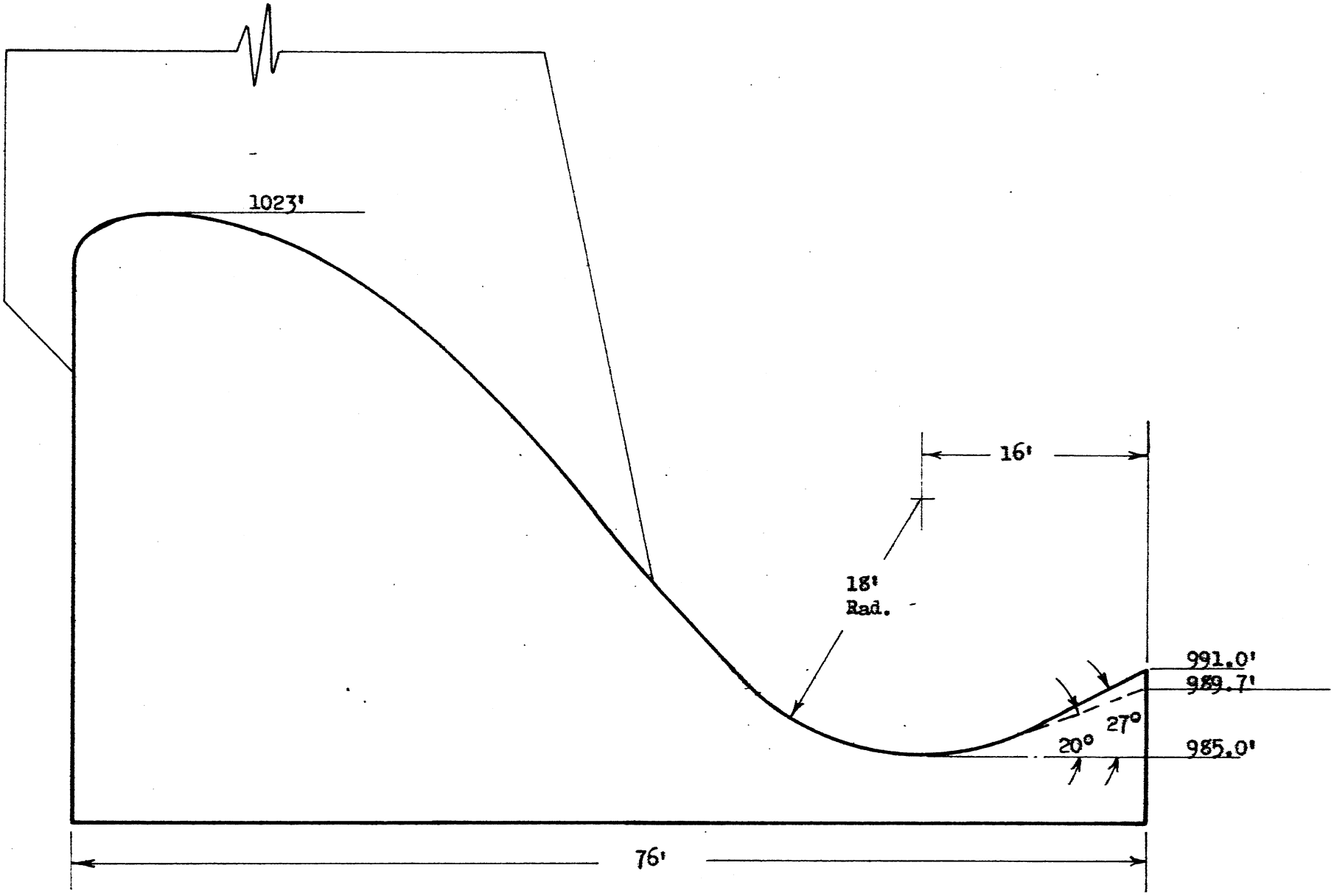
Run No. 23

Discharge for this run was 216,000 cu ft per sec, with a headpool elevation of 1050 ft and tailwater of 1034.5 ft. Head measuring section was located 200 ft upstream of the dam. Red material in the downstream channel was removed to 300 ft below the dam in 30 minutes, and the forces of

the jet was still causing further movement below this point (see Fig. 26).

The coefficients of discharge for the run are as follows:

Time	Q_p	h_v	h_g	L_n	C
minutes	c.f.s	ft	ft	ft	
0	33,200	3.66	27	55.9	3.10
10	33,200	1.72	27	56.5	3.78
20	33,200	1.71	27	56.5	3.78
40	33,200	1.76	27	56.5	3.76



Bucket Design - Third Revision

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

Fig. 16

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM

HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 16
1	1020.2	1042.6
2	1022.3	1031.2
3	1023.0	1027.5
4	1022.9	1026.0
5	1022.5	1025.4
6	1021.9	1024.1
7	1021.1	1023.0
8	1020.2	1020.6
9	1017.5	1019.5
10	1015.1	1015.2
11	1009.1	1008.3
12	1001.5	1006.2

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	16
Q_m	0.910 cfs
Q_p	11,200 cfs
Pool Elev.	1045'
Tailwater Elev.	1002.5'
Gate Setting	One gate open
Bucket Elev.	985'
Apron	20°

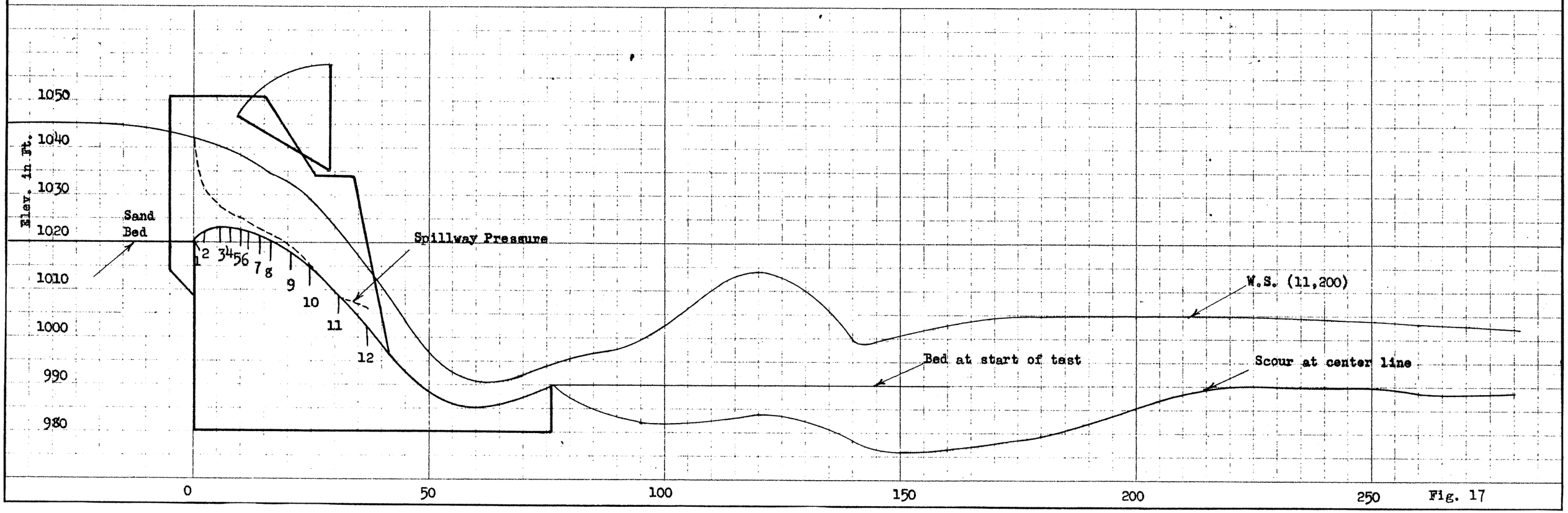


Fig. 17

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 17
1	1020.2	1047.0
2	1022.3	1043.7
3	1023.0	1036.6
4	1022.9	1028.8
5	1022.5	1024.1
6	1021.9	1021.9
7	1021.1	1021.1
8	1020.2	1019.6
9	1017.5	1018.9
10	1015.1	1015.0
11	1009.1	1007.9
12	1001.5	1005.9

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	17
Q_m	0.625 cfs
Q_p	50,000 cfs
Pool Elev.	1045'
Tailwater Elev.	1011'
Gate Setting	1028.3'
Bucket Elev.	985'
Apron	20°

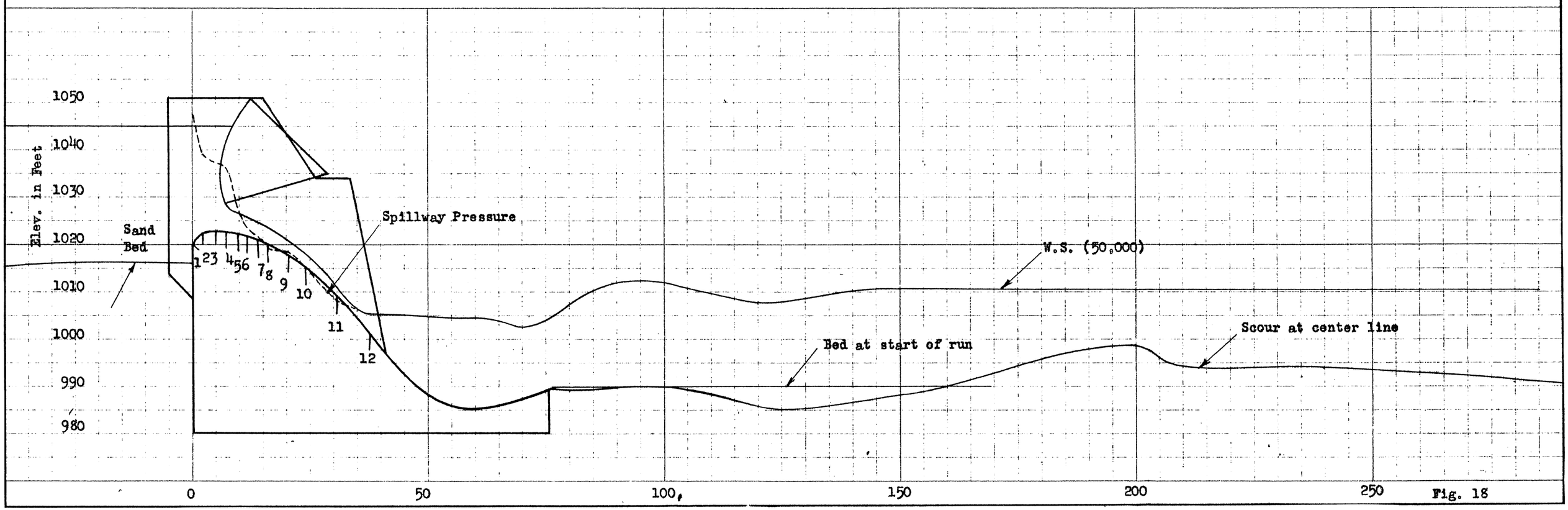


Fig. 18

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 18
1	1020.2	1039.2
2	1022.3	1032.1
3	1023.0	1027.8
4	1022.9	1025.8
5	1022.5	1025.0
6	1021.9	1024.1
7	1021.1	1023.2
8	1020.2	1021.3
9	1017.5	1020.8
10	1015.1	1014.1
11	1009.1	1014.1
12	1001.5	1026.4

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	18
Q_m	2.06 cfs
Q_p	165,000 cfs
Pool Elev.	1045'
Tailwater Elev.	1028'
Gate Setting	All gates open
Bucket Elev.	985'
Apron	20°

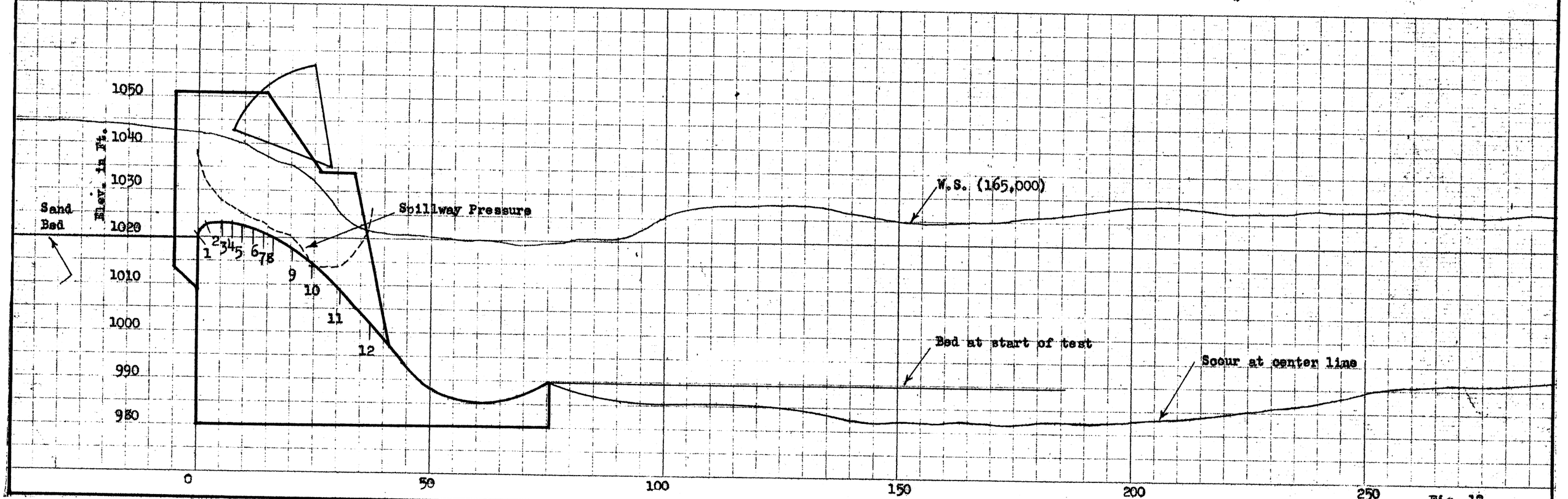


Fig. 19

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	1B
Q_m	2.06 cfs
Q_p	165,000 cfs
Pool Elev.	1048'
Tailwater Elev.	1028'
Gate Setting	All open
Bucket Elev.	985'
Apron	20°

APPROACH CHANNEL SCOUR TEST

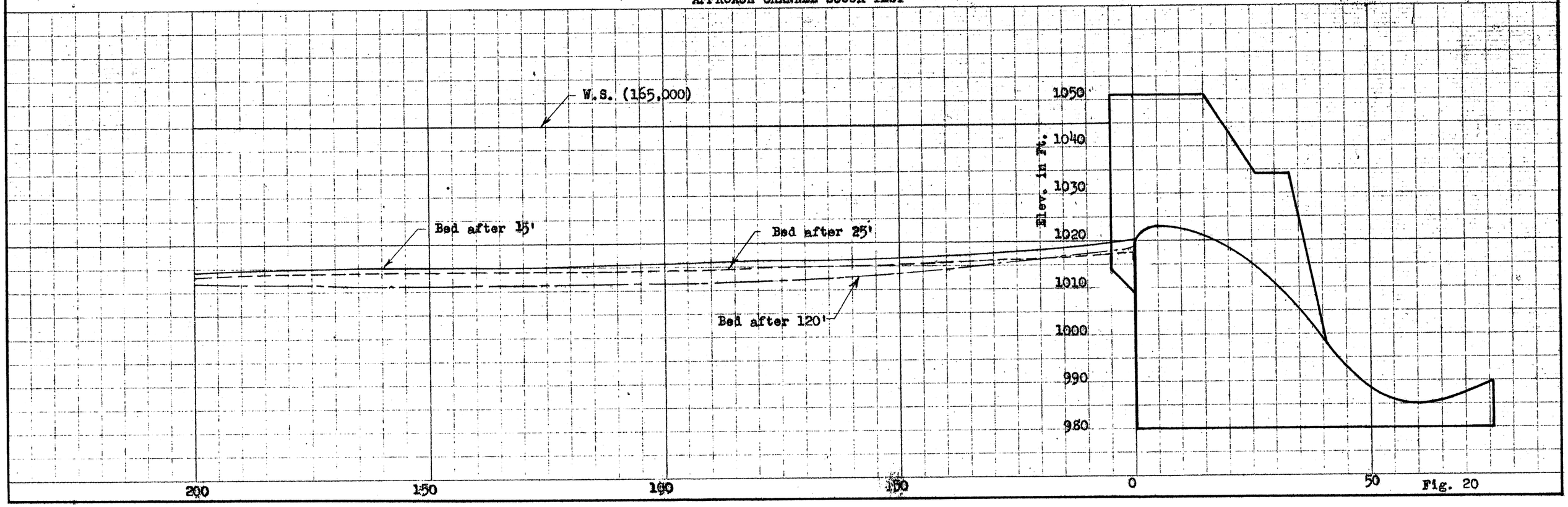


Fig. 20

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	19
Q_m	2.70 cfs
Q_p	216,000 cfs
Pool Elev.	1050'
Tailwater Elev.	1034.5'
Gate Setting	All open
Bucket Elev.	985'
Apron	20°

APPROACH CHANNEL SCOUR TEST

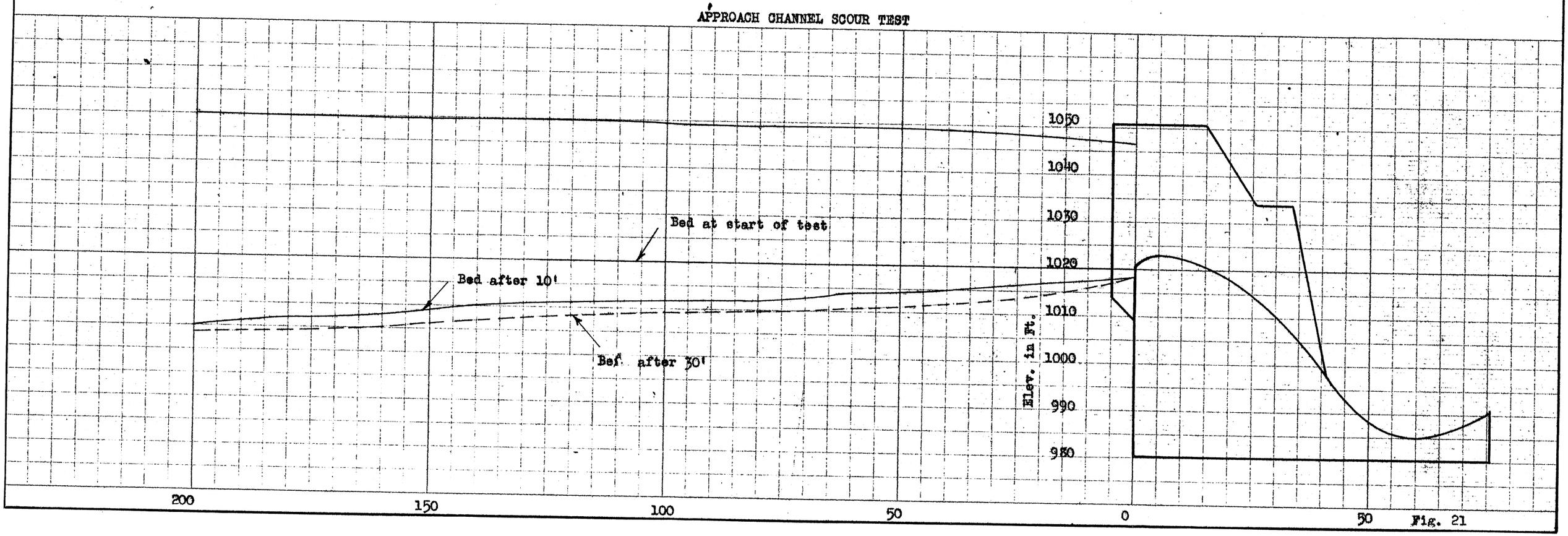


Fig. 21

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 19
1	1020.2	1049.2
2	1022.3	1031.6
3	1023.0	1026.7
4	1022.9	1024.9
5	1022.5	1024.5
6	1021.9	1024.7
7	1021.1	1024.5
8	1020.2	1024.1
9	1017.5	1024.9
10	1015.1	1028.3
11	1009.1	1032.7
12	1001.5	1037.1

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	19
Q_m	2.70 cfs
Q_p	216,000 cfs
Pool Elev.	1050'
Tailwater Elev.	1034.5'
Gate Setting	All open
Bucket Elev.	985'
Apron	20°

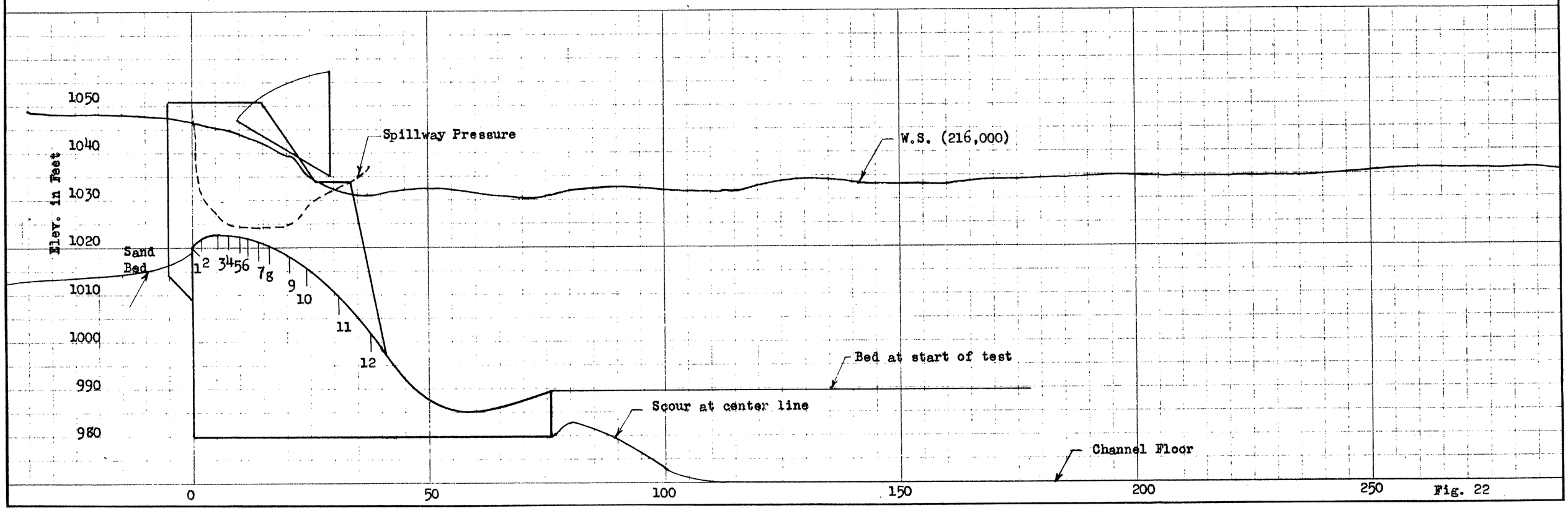


Fig. 22

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 20
1	1020.2	1043.6
2	1022.3	1031.9
3	1023.0	1028.0
4	1022.9	1026.0
5	1022.5	1024.9
6	1021.9	1024.1
7	1021.1	1022.8
8	1020.2	1020.8
9	1017.5	1019.8
10	1015.1	1015.0
11	1009.1	1008.5
12	1001.5	1006.1

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	20
Q_m	0.910 cfs
Q_p	11,200 cfs
Pool Elev.	1045'
Tailwater Elev.	1002.5'
Gate Setting	Center gate open
Bucket Elev.	985'
Apron	27°

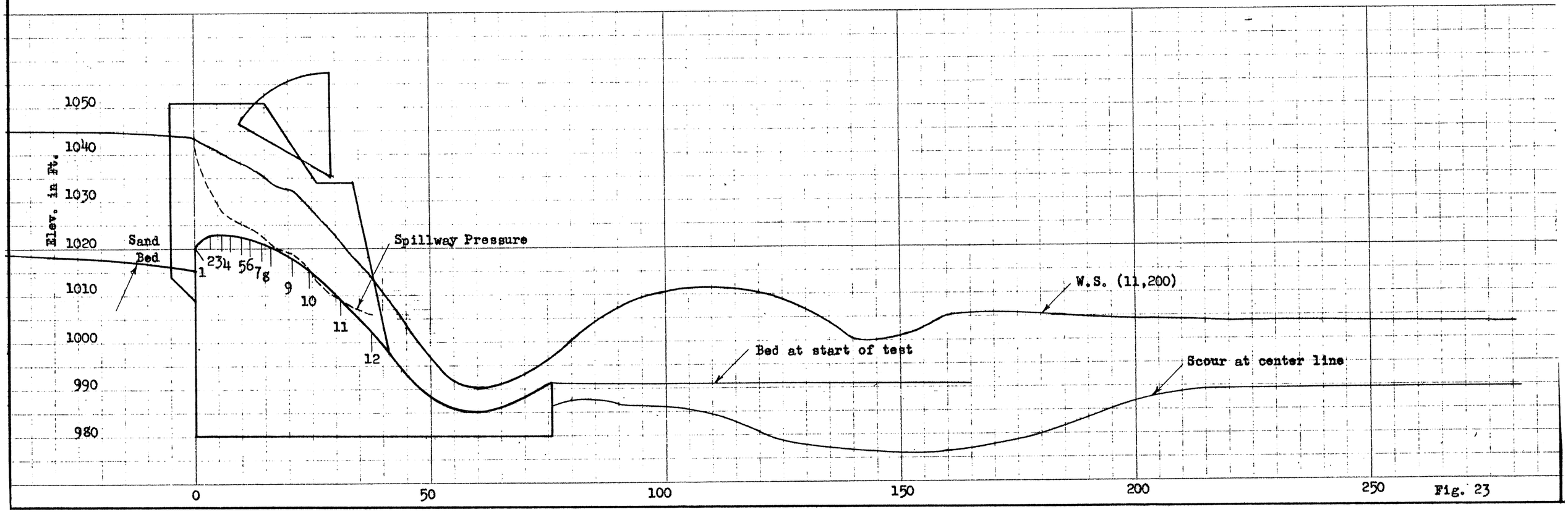


Fig. 23

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 21
1	1020.2	1045.7
2	1022.3	1042.4
3	1023.0	1035.5
4	1022.9	1028.3
5	1022.5	1023.8
6	1021.9	1021.9
7	1021.1	1021.1
8	1020.2	1019.5
9	1017.5	1019.1
10	1015.1	1014.8
11	1009.1	1008.5
12	1001.5	1007.4

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	21
Q_m	0.625 cfs
Q_p	50,000 cfs
Pool Elev.	1045'
Tailwater Elev.	1011'
Gate Setting	1028.3'
Bucket Elev.	985'
Apron	27°

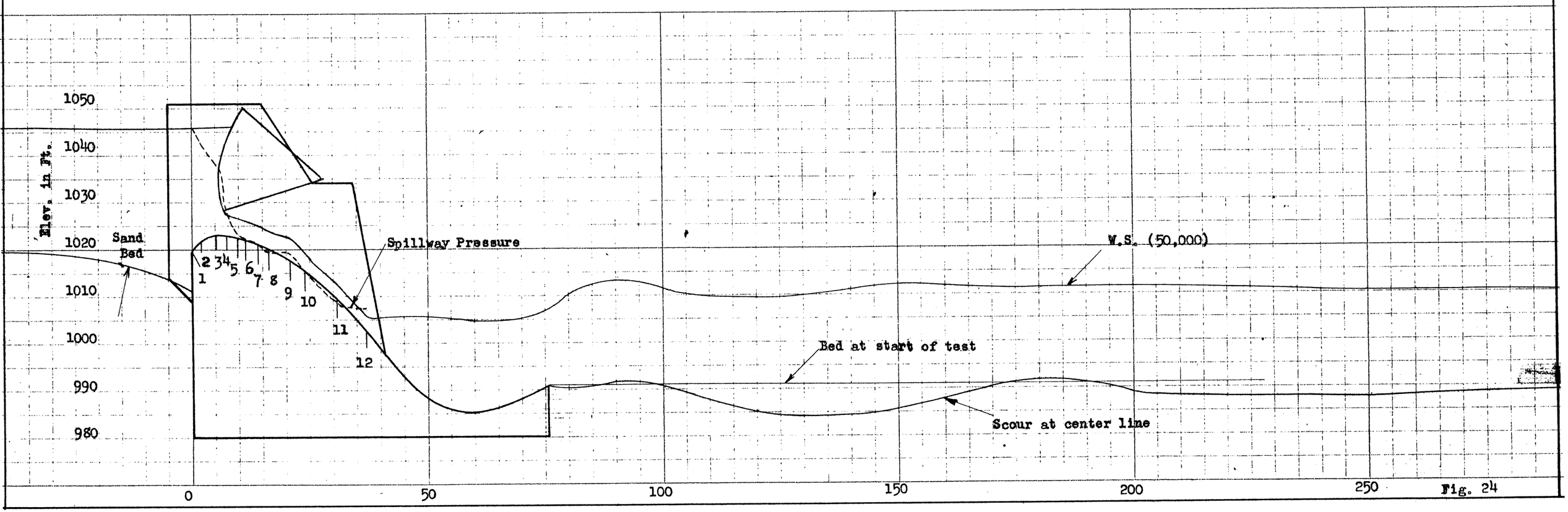


Fig. 24

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	22
Q_m	2.06 cfs
Q_p	165,000 cfs
Pool Elev.	1045'
Tailwater Elev.	1028'
Gate Setting	All gates open
Bucket Elev.	985'
Apron	27°

APPROACH CHANNEL SCOUR TEST

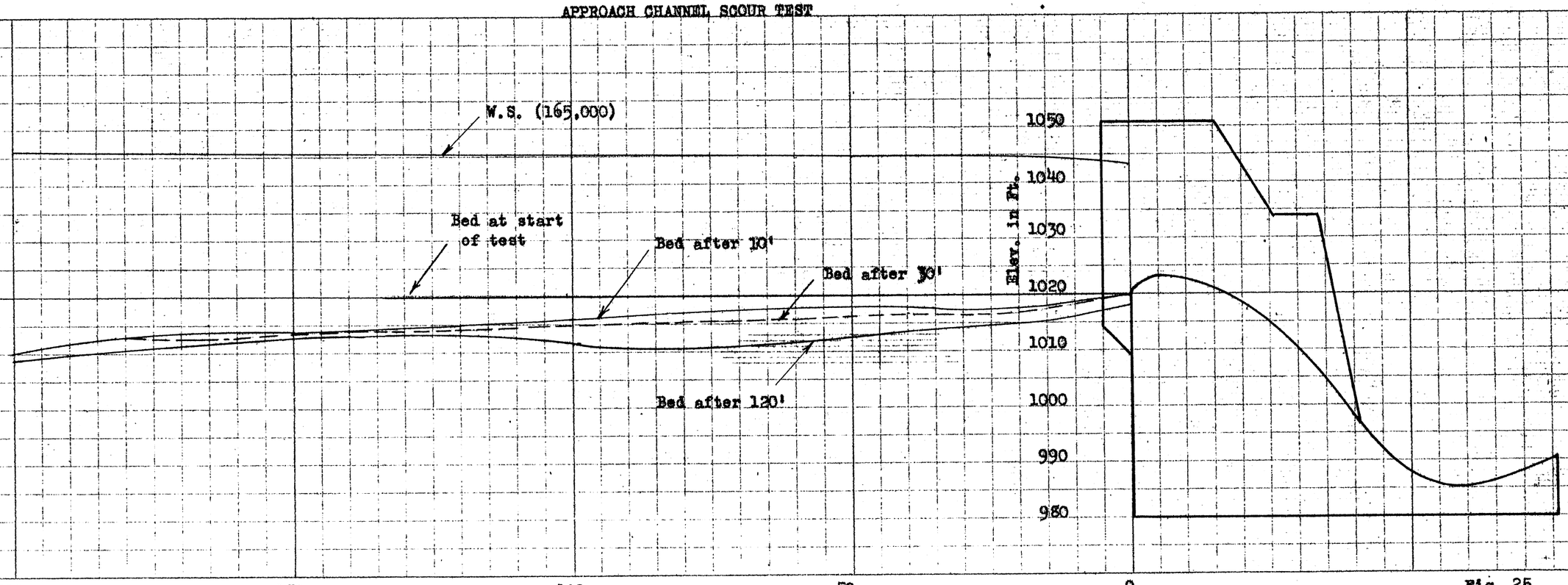


Fig. 25

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 22
1	1020.2	1044.8
2	1022.3	1032.3
3	1023.0	1027.8
4	1022.9	1026.7
5	1022.5	1025.6
6	1021.9	1024.1
7	1021.1	1023.2
8	1020.2	1021.5
9	1017.5	1021.3
10	1015.1	1019.3
11	1009.1	1020.7
12	1001.5	1029.3

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	22
Q_m	2.06 cfs
Q_p	165,000 cfs
Pool Elev.	1045'
Tailwater Elev.	1028'
Gate Setting	All gates open
Bucket Elev.	985'
Apron	27°

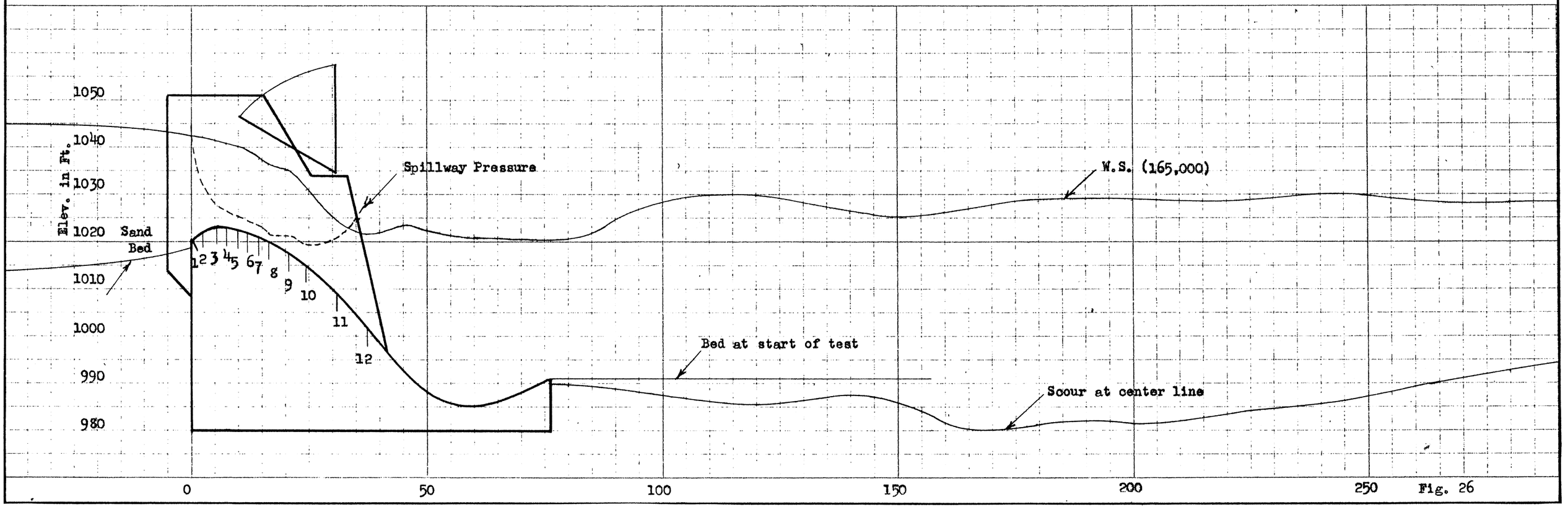


Fig. 26

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	23
Q_m	2.70 cfs
Q_p	216,000 cfs
Pool Elev.	1050'
Tailwater Elev.	1034.5'
Gate Setting	All gates open
Bucket Elev.	985'
Apron	27°

APPROACH CHANNEL SCOUR TEST

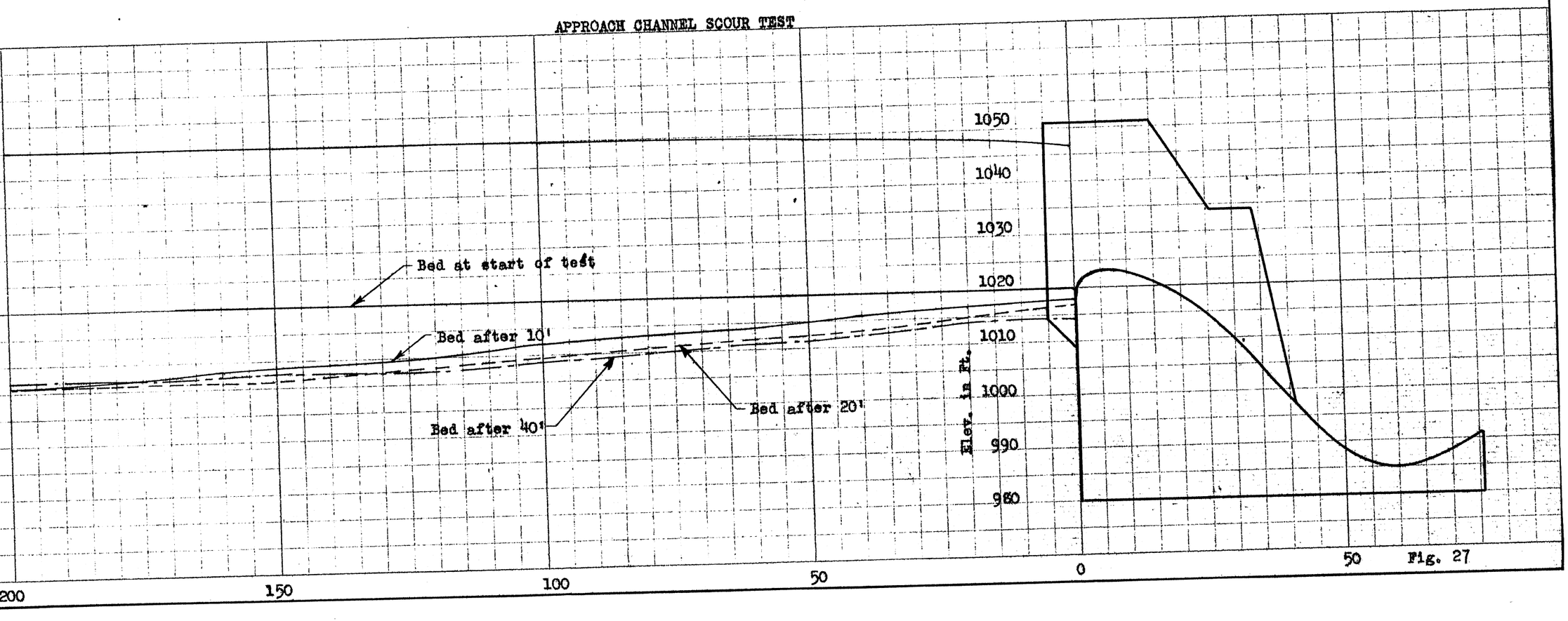


Fig. 27

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES

St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. June 28, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 23
1	1020.2	1048.4
2	1022.3	1031.0
3	1023.0	1026.7
4	1022.9	1025.2
5	1022.5	1024.7
6	1021.9	1024.7
7	1021.1	1024.7
8	1020.2	1024.1
9	1017.5	1025.4
10	1015.1	1028.4
11	1009.1	1034.1
12	1001.5	1037.9

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	23
Q_m	2.70 cfs
Q_p	216,000 cfs
Pool Elev.	1050'
Tailwater Elev.	1034.5'
Gate Setting	All gates open
Bucket Elev.	985'
Apron	27°

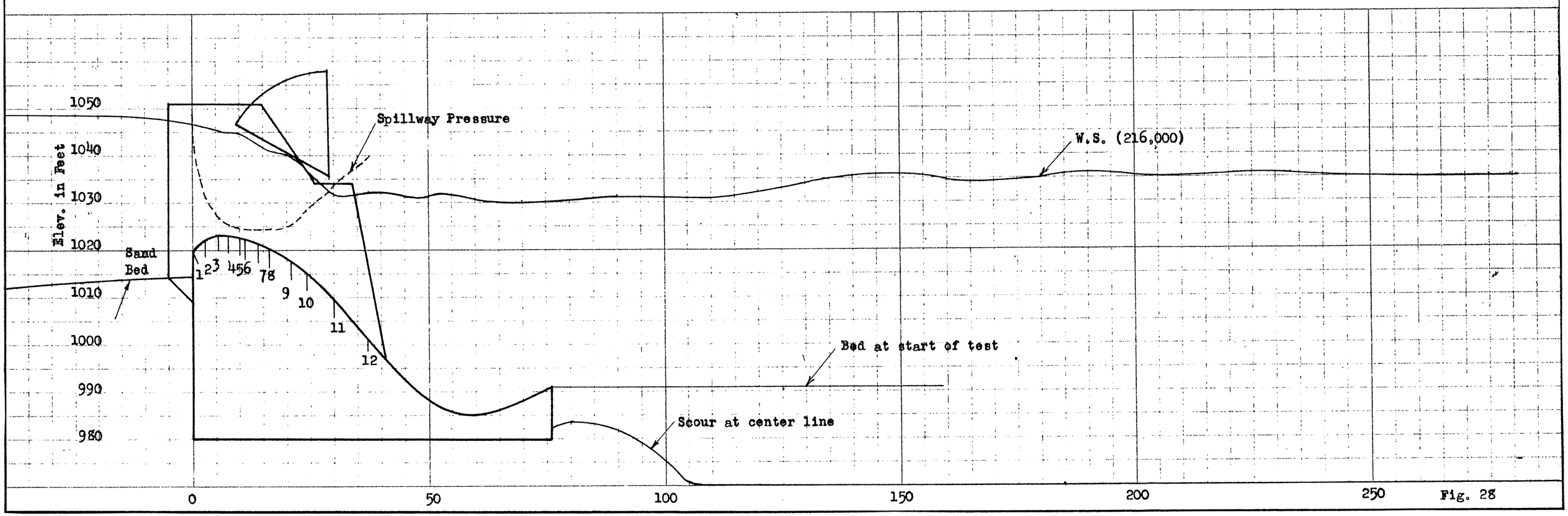


Fig. 28

HYDRAULIC MODEL STUDIES OF HOLCOMBE DAM

as conducted for

THE NORTHERN STATES POWER COMPANY

by

THE ST. ANTHONY FALLS HYDRAULIC LABORATORY

Technical Memorandum No. 4

The model was revised as shown in the sketch marked "Bucket Design-Second Revision." (See Fig. 29) This revision, although dated July 9, was tested before the third revision dated June 28. However, completion of the second revision was suspended to test the third revision series. The bucket elevation was 1013 ft with a 27° apron 16 ft in length.

Run No. 11

Flow through the model with a headpool elevation of 1045 ft and a tailwater of 1028 ft was 140,000 cu ft per sec. This is a reduction of approximately 24,000 cu ft per sec from the discharge as obtained in the previous tests under similar conditions.

The coefficients of discharge for the model during the period of the test appear in the following table:

Time	Q_p	h_v	h_s	l_n	C
minutes	c.f.s.	ft	ft	ft	
0	21,600	2.23	22	57.09	3.27
15	21,600	1.67	22	57.19	3.38
45	21,600	1.67	22	57.19	3.38
120	21,600	1.60	22	57.20	3.39

The head measuring station was located 250 ft upstream from the face of the dam.

The scour hole for this flow is similar in shape and length, but is slightly shallower in depth than for the corresponding flow conditions with a bucket elevation of 991 ft (see Fig. 31).

Run No. 12

With all gates open and the headpool elevation at 1050 ft and a tailwater elevation of 1034.5 ft, the flow through the model was 187,000 cu ft per sec.

The scour in the upstream channel was very rapid at the beginning of the test and the drawdown of the water surface extended a distance of 300 ft upstream from the face of the dam, (see Fig. 32).

The shape and length of the scour hole below the bucket was similar to Run No. 6, but the scour depth was not as much as for a bucket elevation of 991 ft (see Fig. 33).

The discharge coefficients for the model for the duration of the test are:

Time	Q_p	h_v	h_s	L_n	C
minutes	c.f.s.	ft	ft	ft	
0	28,850	2.79	27	56.42	3.24
20	28,850	1.91	27	56.53	3.39
60	28,850	1.55	27	56.58	3.37
120	28,850	1.65	27	56.56	3.37

Run No. 13

With the headpool at 1045 ft and all gates closed to a bottom elevation of 1034.66 ft and a tailwater elevation of 1018.5 ft, the flow through the model was 100,000 cu ft per sec. No erosion was evident in the upstream channel. The scour hole for this test was deeper than that for a bucket elevation of 991 ft. Approximately 10 ft of the toe wall was uncovered by erosion (see Fig. 34). The coefficient of orifice discharge for this test was found to be C = 0.637.

Run No. 14

Discharge through the model with one gate fully open and headpool elevation of 1045 ft was 11,200 cu ft per sec. The tailwater elevation for this run was 1010 ft. No erosion occurred in the upstream channel; however, the scour below the dam was very severe and uncovered the toe wall of the dam to an elevation of 977 ft (see Fig. 34). The coefficient of discharge for this run was:

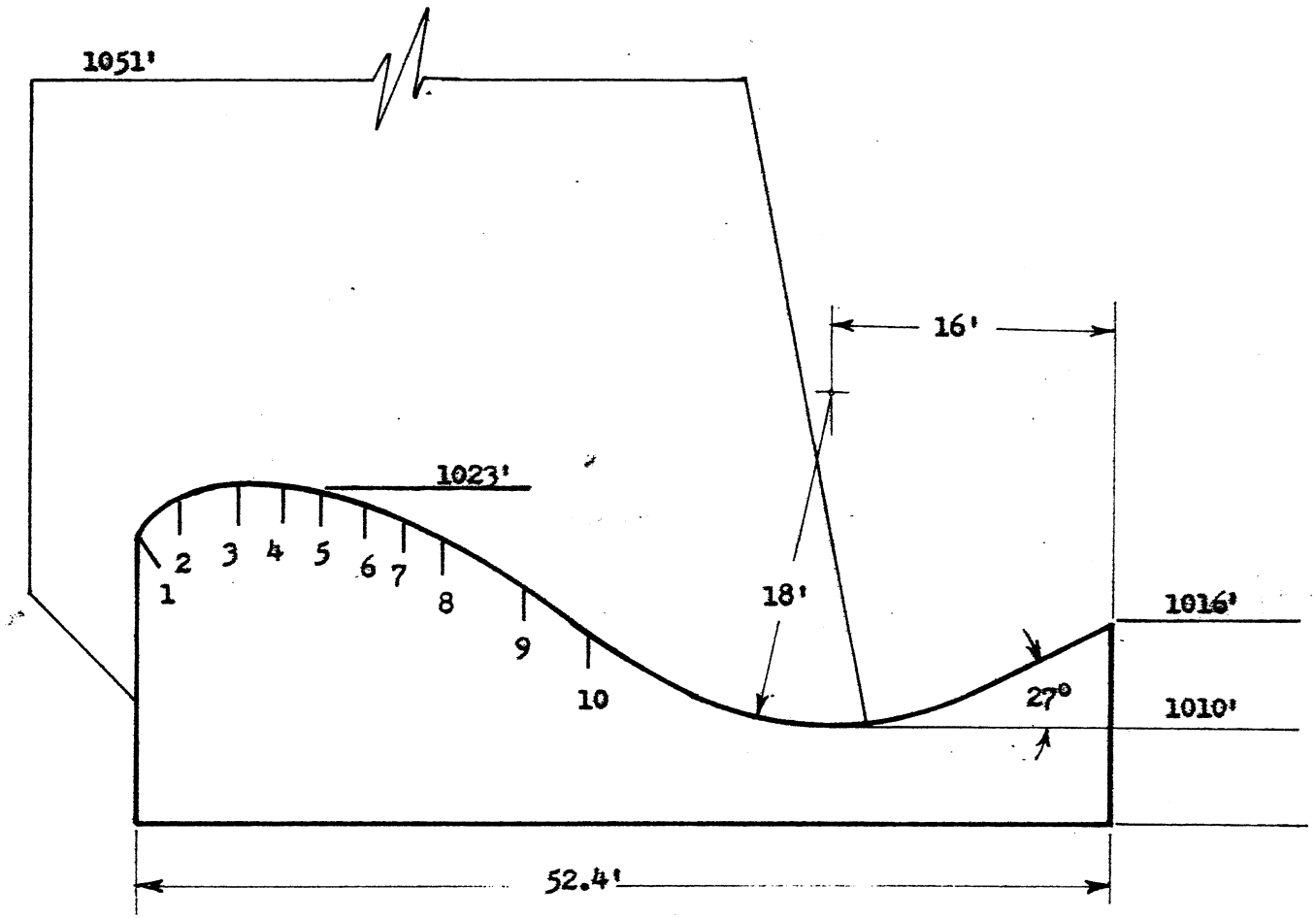
Time	Q_p	h_v	h_e	l_n	C
minutes	c.f.s.	ft	ft	ft	
0	11,200	.601	22	29.86	3.51
105	11,200	.542	22	29.86	3.53

Run No. 15

Flow conditions for this run were identical with Run No. 14 except that the tailwater was at an elevation of 1012 ft, as requested in Mr. Wehmer's letter of June 17.

The scour downstream of the dam was approximately the same as for Run No. 14 (see Fig. 26). Coefficients of discharge are:

Time	Q_p	h_v	h_e	l_n	C
minutes	c.f.s.	ft	ft	ft	
0	11,200	.601	22	29.86	3.51
120	11,200	.560	22	29.86	3.50



Bucket Design - Second Revision

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. July 9, 1948

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. July 8, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	11
Q_m	1.75 cfs
Q_p	140,000 cfs
Pool Elevation	1045'
Tailwater Elev.	1028'
Gate Setting	All open
Bucket Elev.	1010'
Apron	27°

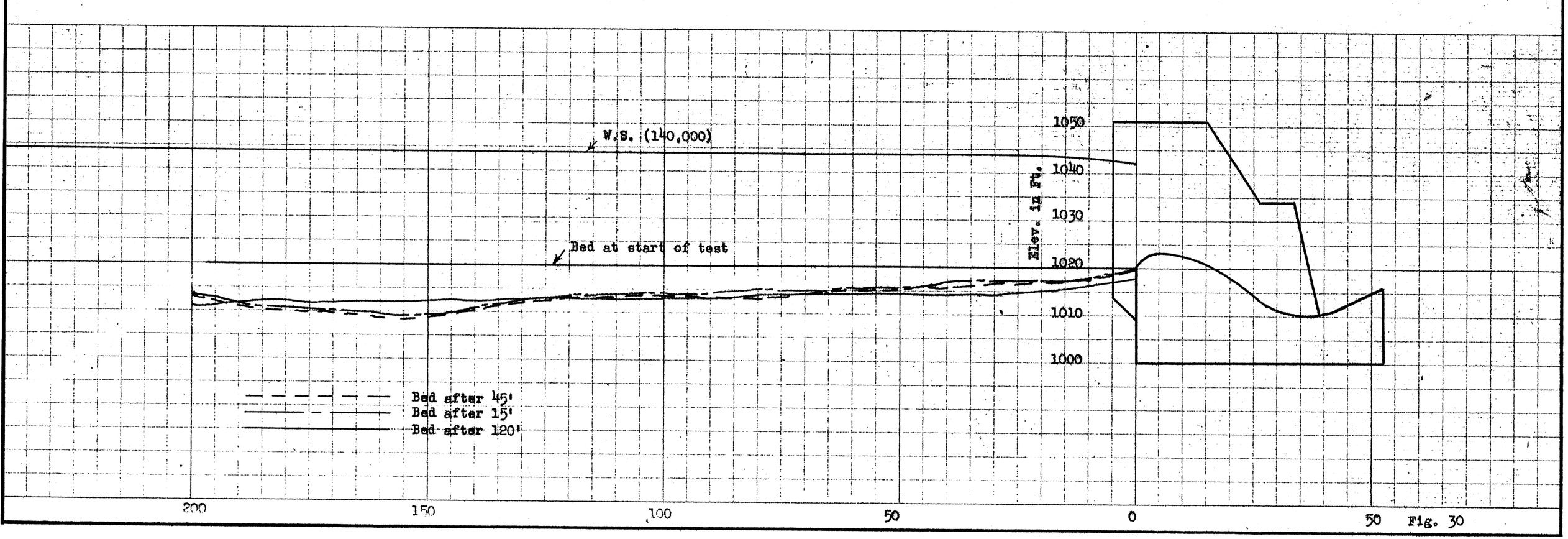


Fig. 30

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. July 9, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 11
1	1020.2	1038.8
2	1022.3	1031.8
3	1023.0	1030.1
4	1022.9	1028.8
5	1022.5	1028.2
6	1021.9	1028.0
7	1021.1	1027.7
8	1020.2	1028.0
9	1017.5	1028.8
10	1015.1	1030.9

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	11
Q_m	1.75 cfs
Q_p	140,000 cfs
Pool Elev.	1045'
Tailwater Elev.	1028'
Gate Setting	All open
Bucket Elev.	1010'
Apron	27°

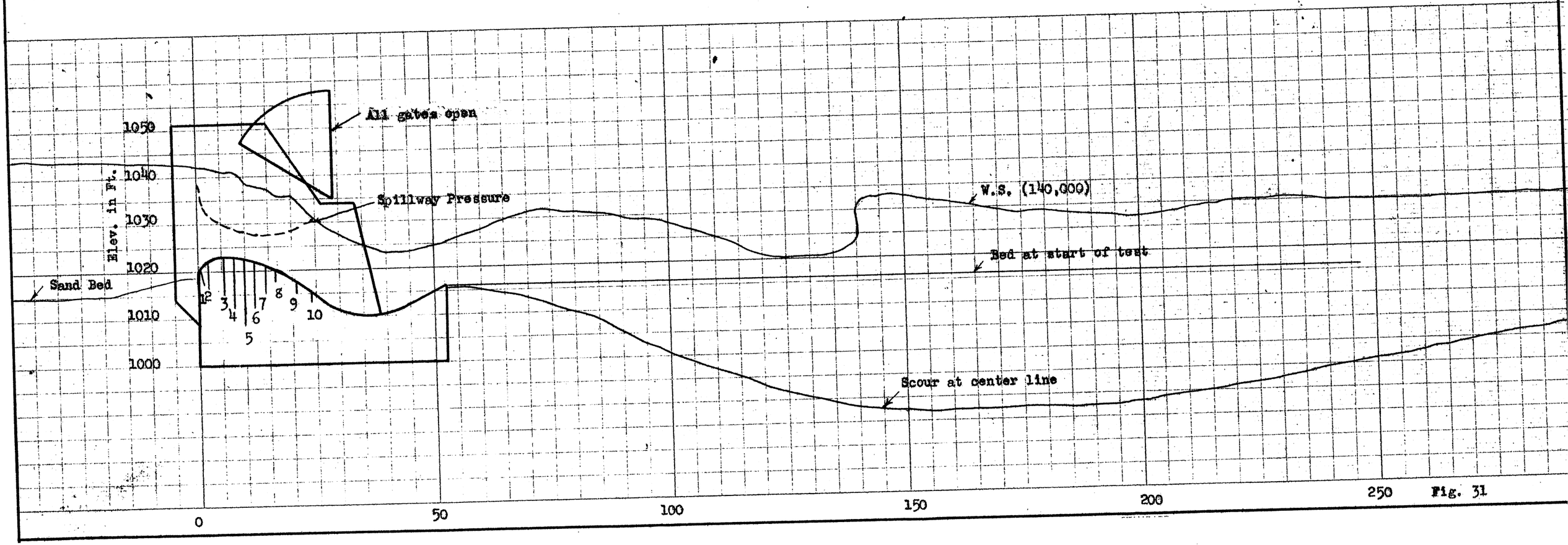


Fig. 31

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. July 8, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	12
Q_m	2.35 cfs
Q_p	187,500 cfs
Pool Elevation	1050'
Tailwater Elev.	1034.5'
Gate Setting	All open
Bucket Elev.	1010'
Apron	27°

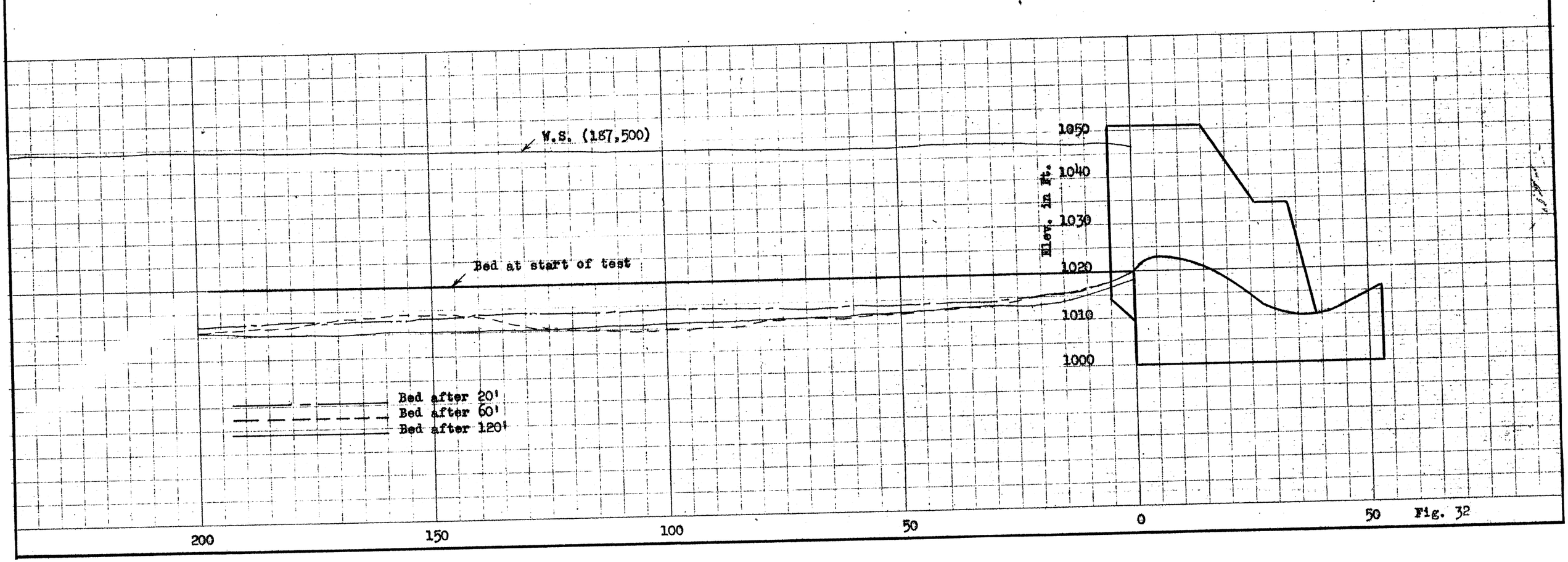


Fig. 32

SPILLWAY PRESSURE

Piez.	Elev.	Run 12
1	1020.2	1047.8
2	1022.3	1034.4
3	1023.0	1030.8
4	1022.9	1029.9
5	1022.5	1030.1
6	1021.9	1030.5
7	1021.1	1031.2
8	1020.2	1032.5
9	1017.5	1034.2
10	1015.1	1039.6

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. July 6, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	12
Q_m	2.35 cfs
Q_p	187,500 cfs
Pool Elevation	1050'
Tailwater Elev.	1034.5'
Gate Setting	All open
Bucket Elev.	1010'
Apron	27°

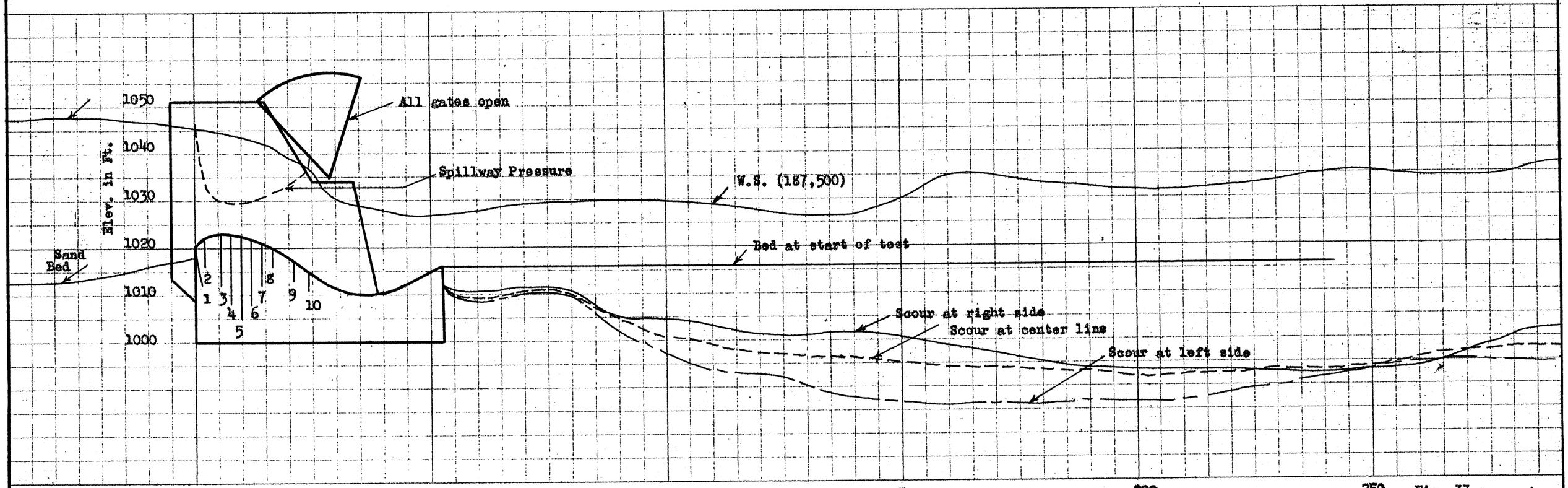


Fig. 33

SPILLWAY PRESSURE

Piez.	Elev.	Run 13
1	1020.2	1045.6
2	1022.3	1036.8
3	1023.0	1032.6
4	1022.9	1028.6
5	1022.5	1025.8
6	1021.9	1023.8
7	1021.1	1022.3
8	1020.2	1021.1
9	1017.5	1021.1
10	1015.1	1027.3

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. July 8, 1948

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing scale	1" = 20'
Run	13
Q_m	1.25 cfs
Q_p	100,000 cfs
Pool Elevation	1045'
Tailwater Elev.	1018.5'
Gate Setting	All gates open to 1034.86'
Bucket Elev.	1010'
Apron	27°

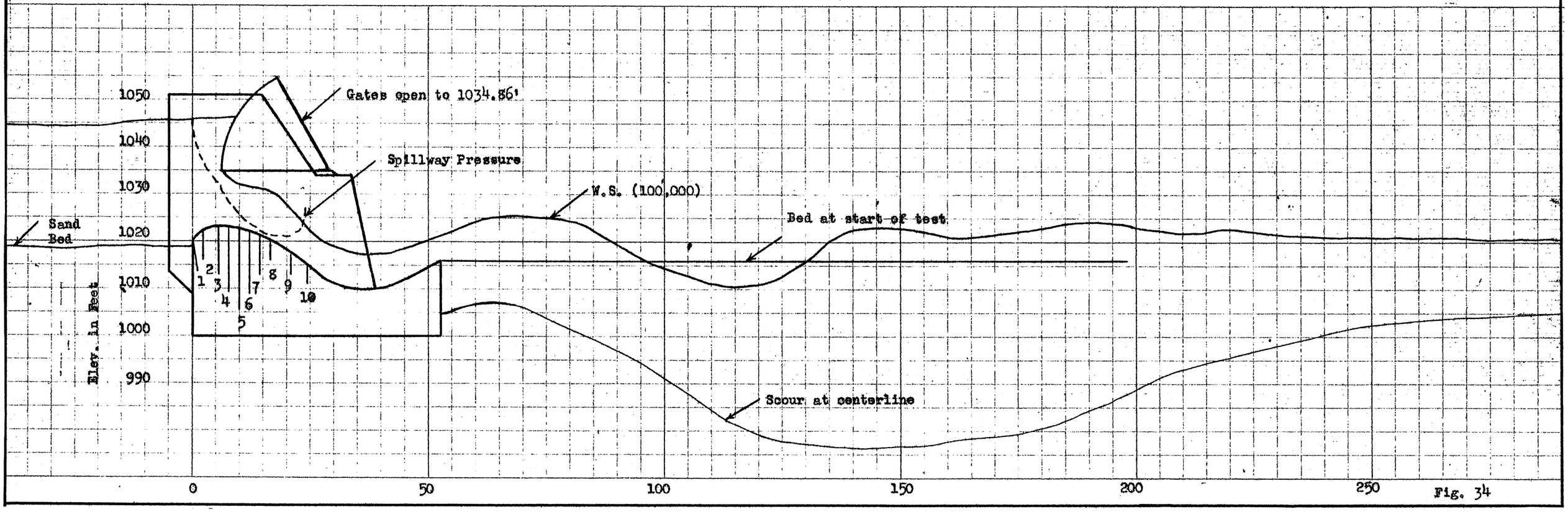


Fig. 34

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. July 9, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 14
1	1020.2	1044.4
2	1022.3	1029.9
3	1023.0	1028.9
4	1022.9	1027.6
5	1022.5	1026.9
6	1021.9	1026.3
7	1021.1	1026.1
8	1020.2	1025.4
9	1017.5	1026.7
10	1015.1	1032.3

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	14
Q_m	.910 cfs
Q_p	11,200 cfs
Pool Elev.	1045'
Tailwater Elev.	1010'
Gate Setting	One gate fully open
Bucket Elev.	1010'
Apron	27°

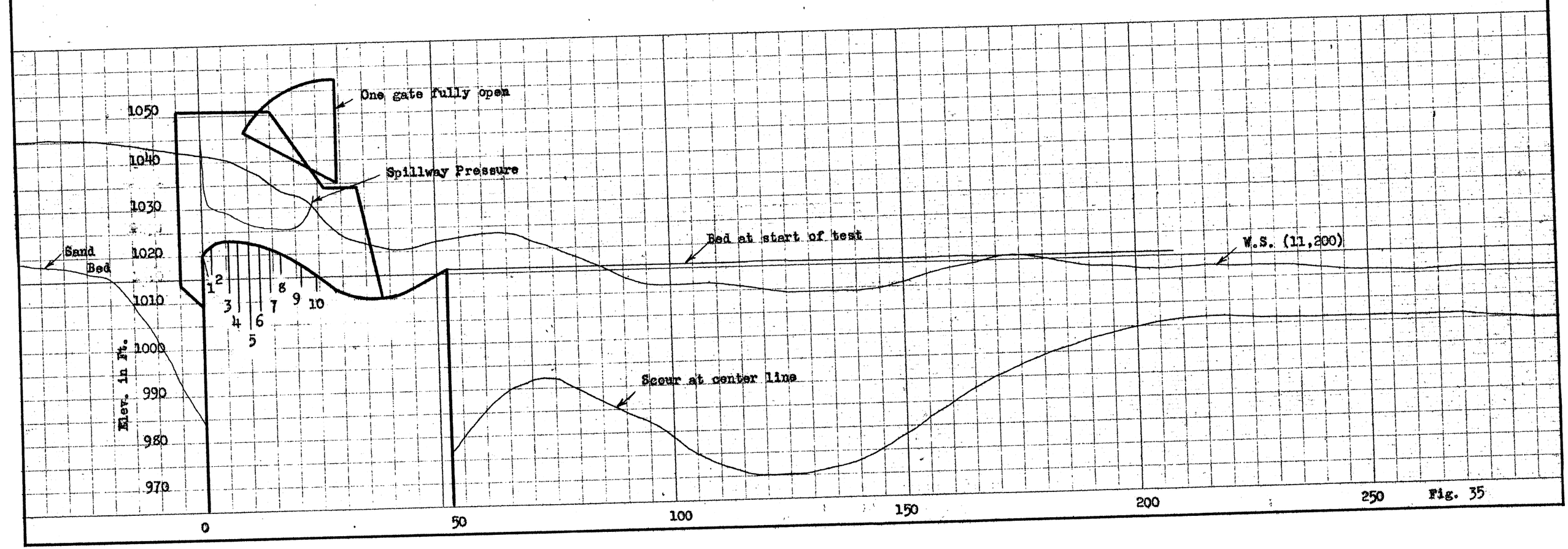


Fig. 35

NORTHERN STATES POWER COMPANY
HOLCOMBE DAM
HYDRAULIC MODEL STUDIES
St. Anthony Falls Hydraulic Laboratory
Minneapolis, Minn. July 9, 1948

SPILLWAY PRESSURE

Piez.	Elev.	Run 15
1	1020.2	1045.6
2	1022.3	1039.2
3	1023.0	1032.3
4	1022.9	1028.4
5	1022.5	1025.2
6	1021.9	1023.4
7	1021.1	1021.7
8	1020.2	1019.5
9	1017.5	1019.1
10	1015.1	1015.5

SPILLWAY SECTION EXPERIMENTS

Scale of Model	1:43.2
Drawing Scale	1" = 20'
Run	15
Q_m	.910 cfs
Q_p	11,200 cfs
Pool Elevation	1045'
Tailwater Elev.	1012'
Gate Setting	One gate fully open
Bucket Elev.	1010'
Apron	27°

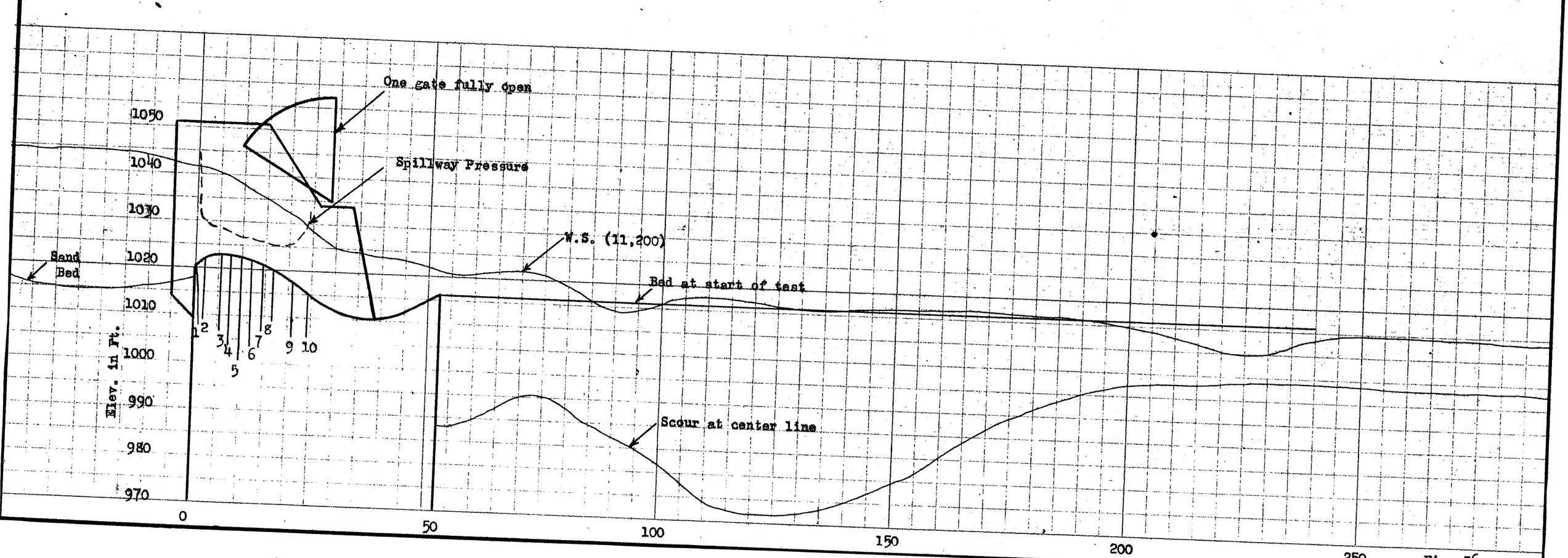


Fig. 36