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HYDRAULIC LABORATORY REPORT NO. 109

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HYDRAULIC MODEL STUDIES OF GRANBY DAM SPILLWAY
COLORADO - BIG THOMPSON PROJECT

By

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Denver, Colorado

March 31, 1942

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
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Laboratory Report No. 109
Hydraulic Laboratory
Compiled by: R. R. Pomeroy

Subject: Hydraulic Model Studies of Granby Dam Spillway - Colorado-Big Thompson Project.

INTRODUCTION

Granby Dam is located about four miles northeast of the town of Granby, Grand County, Colorado (figure 1). The dam is to be a combination earth and rockfill structure having a height of 223 feet above river level. It will intercept the flows of the Colorado River, Willow Creek, Meadow Creek, and Strawberry Creek to form a reservoir with an estimated capacity of 482,860 acre-feet at the maximum water surface, elevation 8275. Water from this reservoir will be pumped into Shadow Mountain Lake and thus made available for delivery through the Continental Divide Tunnel to the Eastern slope.

The outlet works and spillway, with capacities of 500 second-feet and 12,000 second-feet respectively, are located on the left abutment of the dam. The spillway channel is spirally curved downstream from the gate structure, and the channel floor is superelevated. The channel floor intersects the natural slope of the mountainside at a point approximately 365 feet downstream from the spillway crest, from which point the discharge is allowed to flow down the mountainside to the river bed 200 feet below.

PROBLEMS FOR MODEL STUDY

A comprehensive study of the spillway performance was the primary objective in building the model. The outlet tunnel was installed only to observe the effect of the spillway flow on the tunnel exit. The study of the spillway was to stress three principal points:

(1) Determination of the adequacy of the entrance and the feasibility of a satisfactory substitute for the costly warp in the original design.

(2) Determination of the influence of the spiralled curve and superelevated floor of the spillway channel on the flow action.

(3) Determination of the path taken by the flow issuing from the downstream end of the spillway channel and of the possibility that the material disturbed by this flow might be deposited in a location impairing the operation of the outlet tunnel.

CONSTRUCTION OF MODEL

The model of the Granby Dam spillway was constructed to a scale of 1 to 24 and consisted of a head box, outlet tunnel, entrance and channel of the spillway, and a tail box (figure 2). The head box was made of wood with light sheet-metal lining. A cast-iron pipe was used for the outlet tunnel with a gate valve located near the midpoint of the tunnel as the medium for controlling the amount of flow. The spillway entrance and channel were constructed of concrete, the gate structure of redwood and sheet metal. The tail box was constructed in the same manner as the head box and included a hinged wooden and canvas gate for regulating the tailwater elevation. Water columns attached to piezometer openings in the head and tail box were utilized to measure the depth of water entering the gate structure and the height of the tailwater. The bedrock and topography of the spillway area represented in the model was formed of a mixture of concrete, small rocks, and sand.

ENTRANCE TO SPILLWAY

Model tests on the original design indicated that the entrance would perform satisfactorily without any change (figure 3). It was realized, however, that the warp, necessitating a large area of paved surface, would be costly and difficult to construct; therefore, it was desirable to develop a design which would eliminate this feature, if such a design would not seriously impair the performance of the entrance.

The approach to the gate structure has as its left boundary a 1/2:1 slope. In the first of the attempts to develop a new entrance design, a slope of this same magnitude was substituted for the warp on the right side of the approach, a sharp break being formed by the intersection of this slope and an extension of the 3:1 slope of the upstream face of the dam (figure 4). It was this sharp break, extending from the floor of the approach channel to an elevation above that of the maximum water surface, which appeared to be responsible for the undesirable flow conditions obtained in the design. Excessive turbulence caused by the inability of the flow to accomplish such a rapid change in direction at relatively high velocities was apparent.

Numerous designs were also tested in which flatter slopes were substituted for the 1/2:1 slope. These substitutions of flatter slopes were considered to be possible solutions because they placed the sharp corner formed by the intersection of the two slopes at a greater distance from the gate structure and made the drop from the 3:1 slope of the dam face to the floor of the entrance less abrupt. None of the variations tested reduced the unsatisfactory flow conditions to an extent deemed necessary for an adequate design.

The final design differed in that an intermediate slope was used between the 1/2:1 and 3:1 slopes, thus reducing the abruptness of transition from one to the other (figures 5 and 15). It also allowed the highest point on the sharp break to be lowered to approximately elevation 8265.0, an elevation which is below the water surface of all flows above 4000 second-feet. Thus, under the conditions most conducive to high velocities and subsequent turbulence, the effect of the break was at least partially damped because of its origin within the body of liquid and not on the surface. More gradual increases in velocities also resulted from the less abrupt drop to the floor of the entrance and the less abrupt decrease in the cross sectional area of the approach.

Extensive tests to determine the discharge and coefficient curves of this entrance (figure 6), revealed that the discharge for any water surface elevation was as great for this design as it had been for the first design. A comparison was also made of the coefficients of discharge for this entrance with those determined from previous model tests wherein the entrance approach conditions, position of gates, and shape of crest differed materially. As a medium in making such a comparison, the coefficient of discharge, calculated from the formula $Q = 2/3\, CL\sqrt{2g}\, (h_1^{3/2} - h_2^{3/2})$, was plotted against h_1/d, the ratio of the head above the gate seat to the gate opening (figure 7).

The resulting curve, covering a wide range in gate openings, shows that the coefficients for all the entrances, including Granby, can be considered equal for corresponding values of h_1/d, provided that the ratio of h_1 to d is not less than 2.25. In other words, it is only for values of h_1/d below 2.25 that the coefficient is appreciably influenced by the approach conditions. The depth of approach is one of the prime factors causing differences in the value of the coefficient, another being the crest shape.

All the model tests indicated that the performance of this design would compare favorably with that of the original, which was adequate in every respect. The reduction of turbulence to a minimum, the satisfactory entrance coefficients, and the saving in cost and ease of construction to be accomplished by the elimination of warped surfaces, made this design the logical choice.

A comparison of the right approach of the entrance on the final design prototype drawing (figure 16) with that on the model drawing (figure 15) shows a difference in the length of the 1/2:1 slope of approximately 2.5 feet prototype. The increase in length on the prototype design was made in order that the slope of the plane surface joining the 3:1 and 1/2:1 slopes would become 2:1, thus simplifying construction. The change was considered so slight as to make further model tests unnecessary.

SPILLWAY CHANNEL

The channel of the spillway on Granby Dam is unusual in that it is curved in plan so that there is an angle of approximately 24 degrees between the extension of the center-line of the gate structure and the center-line of the channel at its downstream end (figure 2). The original design provided that this change in direction of flow would be accomplished as gradually as possible by spiraling the curve, and it also superelevated the floor within the limits of the curve in order to prevent the piling of the flow on one side of the channel.

The channel, as originally designed, functioned properly, and no changes were made in either the curve or the superelevation. It was, however, decided to line the floor and the sides to a height of 15 feet with concrete in order to improve flow conditions and increase the velocity of flow at the downstream end. This increase in velocity seemed desirable because of the effect it would have on the path of flow after leaving the spillway.

EROSION AT DOWNSTREAM END OF SPILLWAY

It was fully realized before any model tests had been made that there would be considerable erosion caused by the spillway discharge in reaching the bed of the river. The questions of the extent of this erosion and where the disturbed material would be deposited had to be answered by model tests. The location of the deposit was important in that it might have a detrimental effect on the operation of the outlet if it were too near the downstream end of the tunnel.

Under the conditions existing within the area in question, the four most important factors influencing location and amount of erosion and the location of the deposition of eroded material would be (a) the quantity and velocity of the flow causing the erosion, (b) the direction of the general slope of the bed rock and top soil surfaces, (c) the amount of top soil present in the eroded area, and (d) the general characteristics of the erodible material. Of these factors, only the last is virtually impossible to similate on a model, and it is this last consideration which becomes increasingly important as the angle of repose of the top soil and the slope of the medium supporting it increase.

The overburden on Granby dam site consists of slide rock, glacial outwash gravels, river sand and gravels, and slope wash, the latter composed of a mixture of soil, sandy clay and rock fragments which range in size from pebbles up to large boulders. The slope wash is 5 to 10 feet deep on the upper slopes and thickens to as much as 45 feet on the lower slopes. That the impact of the water would be great enough to sweep away this highly compacted soil and rock as quickly as the sand and rock used in the model, is unlikely. The erosion pattern might eventually become the same on the prototype as on the model, but the difference in the relative time necessary for it to assume that shape would have an effect on the extent and location of the final depositions. Because of this limitation, the model was not expected to indicate the exact rate and amount of erosion which would occur, but only an approximation of the direction the flow would eventually assume and whether or not deposition of eroded material would occur in a location likely to interfere with the operation of the outlet.

Care was used in trying to make the surface elvations of the bedrock and topsoil accurate on the model, but difficulty was encountered in the case of the bedrock, because of lack of information as to contours and outcrops. Very few test pits had been dug in the area immediately below the downstream end of the spillway, and the extent and location of outcrops were not adequately defined. The bedrock was placed in accordance with the available data, but its possible inaccuracy was recognized.

In testing, the outlet was operated at the maximum discharge of 500 second-feet and only the leakage from the gates was allowed to flow through the spillway. This condition was maintained for some time, and resulted in the erosion pattern shown in figure 8. The spillway gates were then slowly opened until the maximum discharge of 12,000 second-feet was flowing through the spillway (figure 9). After operating the model under this condition of maximum discharge for one-half hour, spillway gates were closed and the erosion and deposition observed (figure 10).

The path taken by very low discharges through the spillway was such that most of the resultant deposition partially blocked the outlet exit. As the discharge increased and the velocity of the water became sufficient to resist the tendency to follow a path following the direction of the general slope of the surfaces of the top soil and bedrock, the line of flow gradually became straighter. This action did not, however, remove the material already deposited in front of the outlet exit by the smaller flow.

The problem then was one of evolving a method by which the smaller discharges could be forced to follow a path whereby the resultant deposition would occur in some less objectionable location. The most obvious method was that of excavating a pilot channel which, eliminating the necessity for the water to cut its own channel, would allow guiding the discharge to a place where the erodible material carried by it could be deposited without harm. This scheme was successful, but the excavation necessary to create such a channel on the prototype would be additional expense.

The other method considered as a means of attacking the problem involved two changes at the downstream end of the lined spillway. The length of the spillway was increased by ten feet, at the downstream end, and a lip with an average height corresponding to three feet on the prototype structure was placed across the end of the lined section. The crest of this lip varied in elevation, the lowest point occurring at the point of intersection with the left spillway wall. It was thought that these two changes would establish a channel for the flow of water as far as possible from the outlet exit, because the leakage from the gates, the means by which this channel would be started, would tend to flow over the lowest elevation on the crest of the lip and would be thrown outward by the lip and added spillway length in such a manner that the distance it would travel before tending to curve toward the outlet exit would be increased.

There was no indication that the lip helped in any way to attain this objective, so it was removed. The 10-foot length added to the spillway was retained, however, as it seemed to have some beneficial effect in directing the higher discharges in the path desired.

Since the model tests indicated that the conditions below the spillway depended on the authenticity of the bedrock and overburden contours, a request was made that more geological information concerning the site be furnished. Several test pits were dug in the area in question. The contours of the bedrock as defined by information from these test pits and rock outcrops as shown on a geologic map were incorporated in the model to make it more nearly simulate the prototype. The change had a tendency to decrease the slope of the surface toward the outlet, and it seemed probable that the location of deposition would not be as unfavorable.

Tests comparable to those on the original arrangement were made. The gates were slowly raised until a maximum discharge of 12,000 second-feet was flowing through the spillway, this flow being maintained for one-half hour. The results (figures 11, 12, and 13) showed the expected improvement. The channel cut by the low flows in finding a path down the slope emerged much further from the outlet exit; and, while eroded material was still deposited in that vicinity, an adequate channel was cut through it by the combined flow from the outlet and part of the flow from the spillway.

It was also a matter of conjecture as to how the final erosion pattern would be changed if the gates were opened rapidly instead of slowly. The eroded material was replaced and the maximum flow of 12,000 second-feet was discharged through the spillway by suddenly opening the gates. A comparison of the difference in erosion patterns made by rapid opening and slow opening is shown in figure 14.

The possibility that the erosion pattern as obtained in the model tests is not necessarily a true representation of that which will occur on the prototype structure must be emphasized again. It is probable, however, that the model erosion pattern represents a worse condition than the final pattern on the prototype. Because of the characteristics of the top soil material at the dam site, as compared to those of the loosely compacted material used on the model, it is natural to assume that the process of erosion will be much slower on the prototype structure than model test results would indicate. Such a retarding effect on the erosion process would give the discharge from the outlet more opportunity to sluice an adequate channel through the depositions from the spillway area, and the risk of such a channel being clogged by more deposition would be considerably lessened. For this reason, the results of the model erosion tests are believed to indicate that the danger of seriously hampering the outlet discharge is small.

CONCLUSIONS

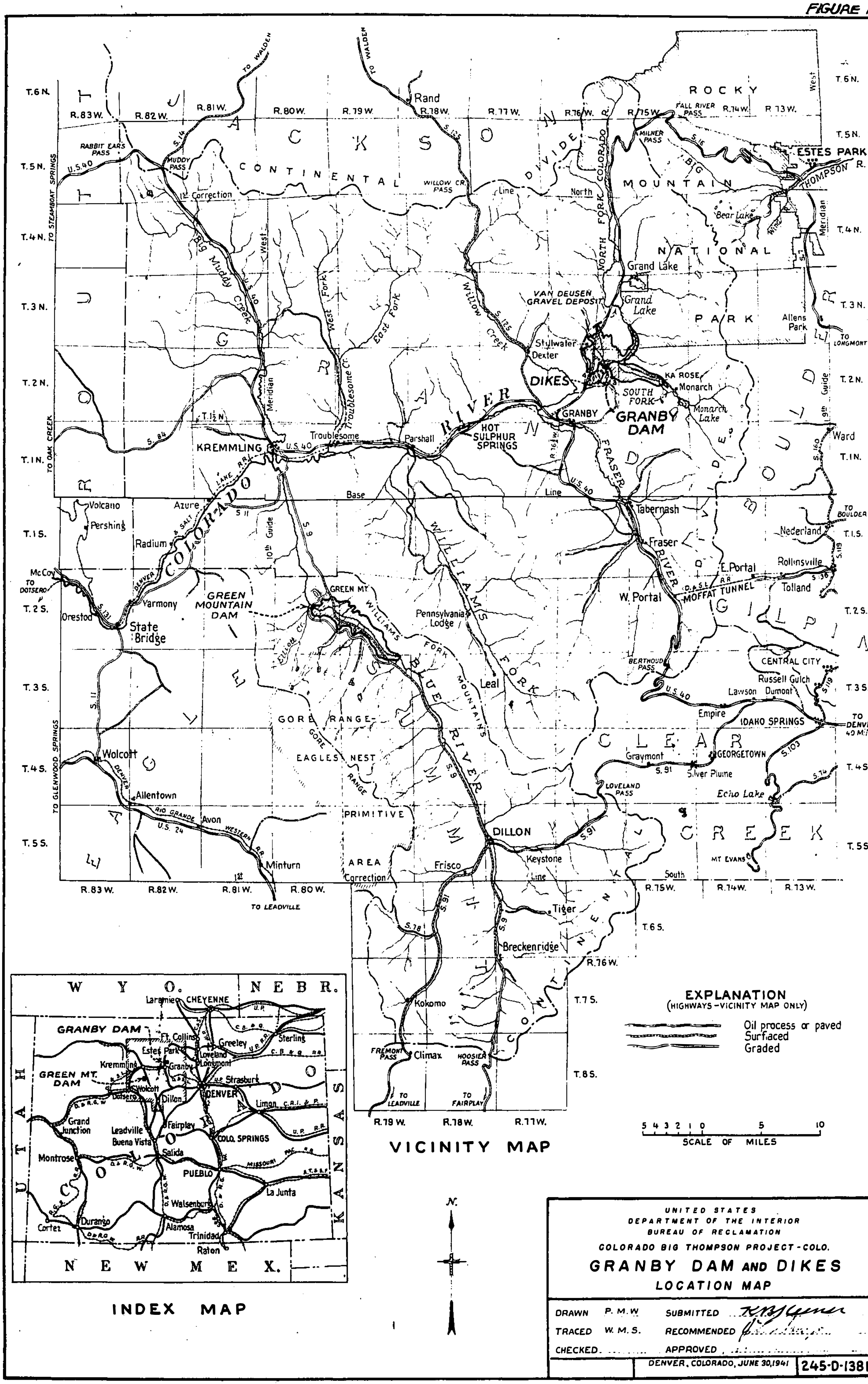
(a) A spillway entrance transition consisting of a series of plane surfaces gave satisfactory results for all reservoir elevations. It was used to replace the warp shown in the original design because of its advantages of smaller initial cost and ease of construction (figure 15).

(b) The performance of the spillway channel as originally designed was satisfactory. Lining the channel with concrete improved the flow conditions and increased the velocity of flow. Such an increase in velocity will be instrumental in straightening the flow path downstream from the channel. A height of 15 feet was suggested as being sufficient for the lining of the walls.

(c) An addition of 10 feet made to the length of the spillway at the downstream end was beneficial in directing the higher discharges in the path desired immediately below the spillway channel.

(d) Although the model erosion pattern may not be an exact representation of that which will occur on the prototype structure, it is a qualitative indication of the prototype conditions to be expected. When the model results are judged in this manner, it appears probable that the erosion and consequent deposition will not interfere seriously with operation of the outlet.

FIGURE 1.



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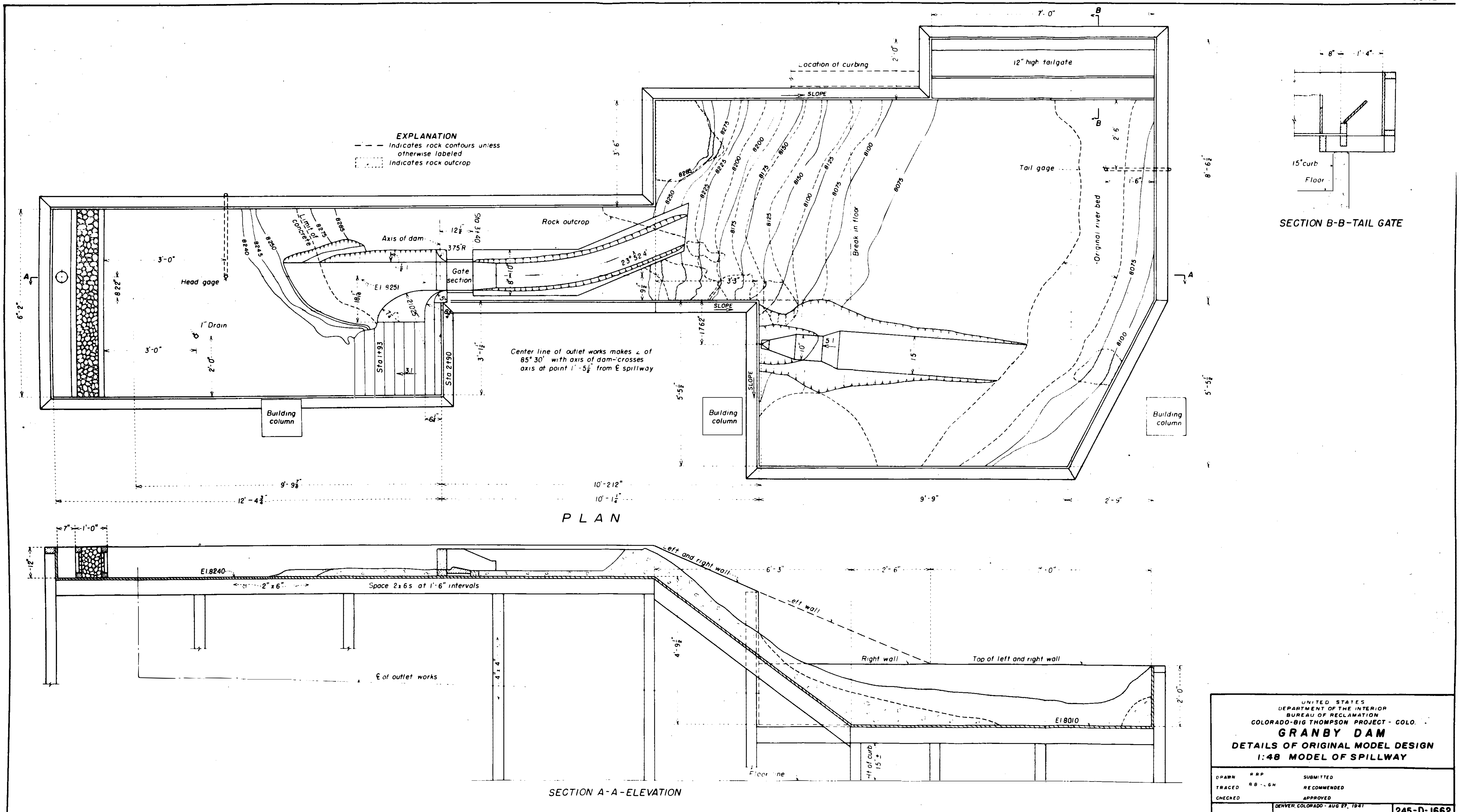
COLORADO BIG THOMPSON PROJECT - COLO.

GRANBY DAM AND DIKES
LOCATION MAP

DRAWN P.M.W.	SUBMITTED [signature]
TRACED W.M.S.	RECOMMENDED [signature]
CHECKED	APPROVED ....
	DENVER, COLORADO, JUNE 30, 1941 — 245-D-1381



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BUREAU OF RECLAMATION
COLORADO-BIG THOMPSON PROJECT - COLO.

GRANBY DAM

DETAILS OF ORIGINAL MODEL DESIGN

1:48 MODEL OF SPILLWAY

DRAWN R.R.P. SUBMITTED
TRACED R.B.-G.H. RECOMMENDED
CHECKED APPROVED

DENVER, COLORADO - AUG 27, 1941

245-D-1662

ENTRANCE TO SPILLWAY

MAXIMUM FLOW OF 12,000 SECOND-FEET THROUGH ENTRANCE.

ORIGINAL DESIGN

ENTRANCE TO SPILLWAY WITH WARP CHANGED TO SHARP CORNER.

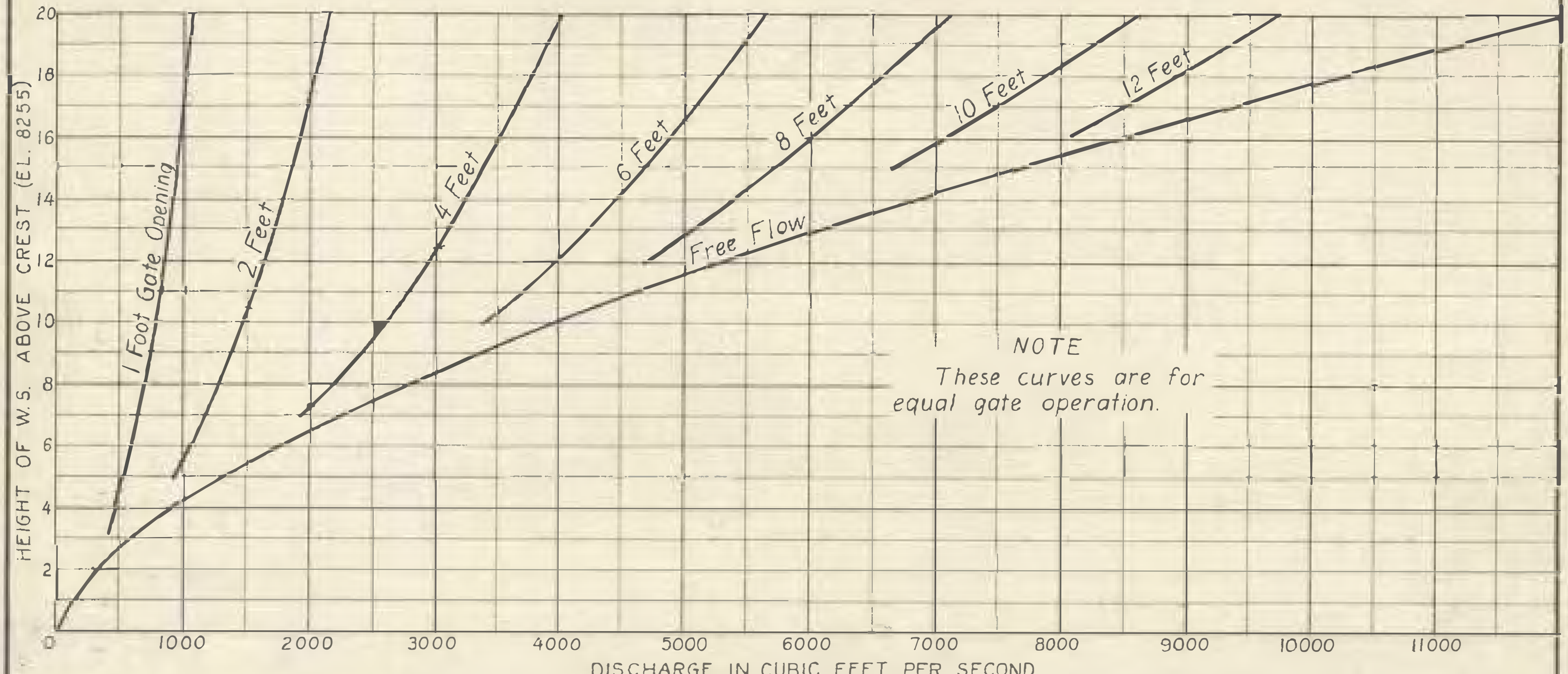
MAXIMUM FLOW OF 12,000 SECOND-FEET THROUGH ENTRANCE.

DESIGN NO. 2

ENTRANCE TO SPILLWAY WITH TWO PLANE SURFACES SUBSTITUTED FOR WARP.

MAXIMUM FLOW OF 12,000 SECOND-FEET THROUGH ENTRANCE.

FINAL DESIGN



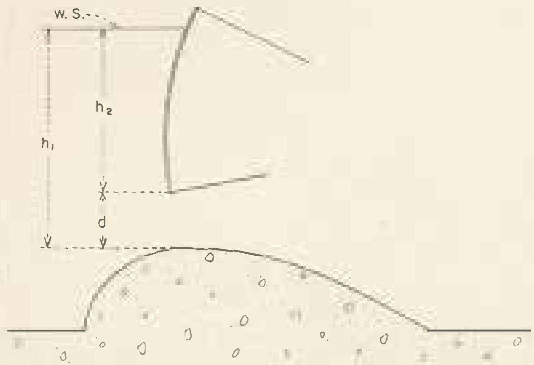
GRANBY DAM SPILLWAY

SPILLWAY DISCHARGE CURVES

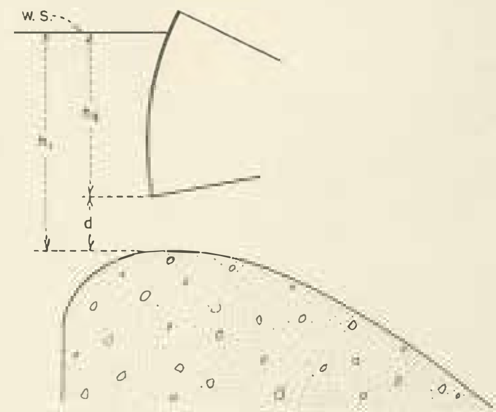
12-13-41 R.R.P.

FIGURE 6

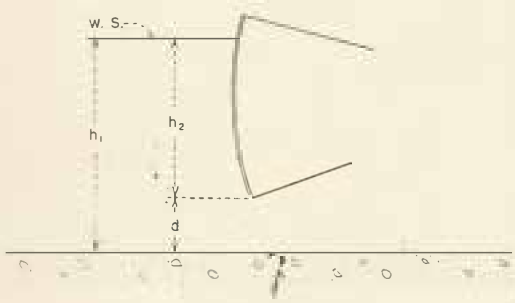
FIGURE 7



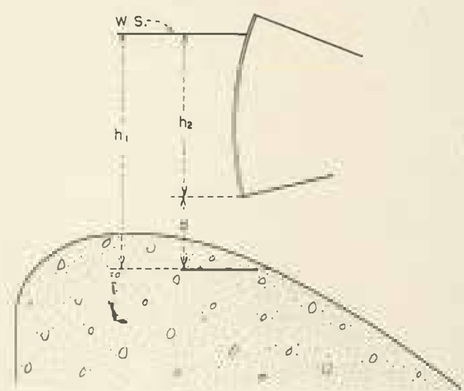
BULL LAKE AND GRANBY



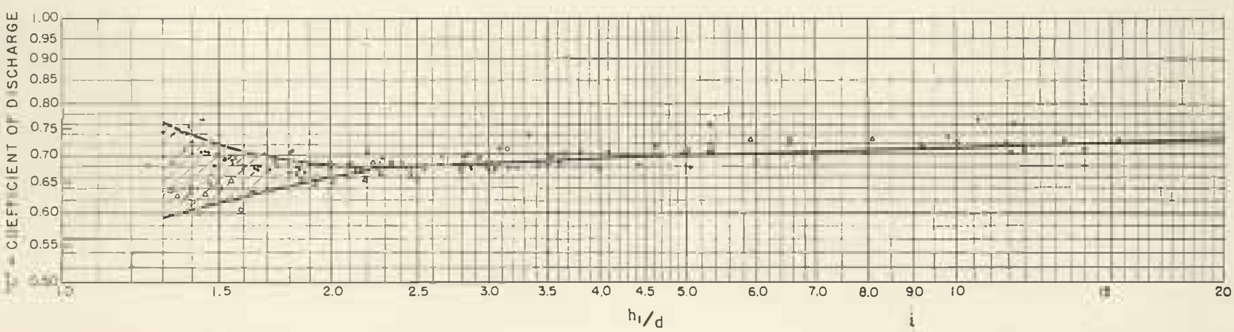
STEWART MTN. AND WHEELER



HORTON'S



CADDOA



NOTE : The coefficient of discharge was calculated from the formula $Q = 2/3\, CL \sqrt{2g}\, (h_1^{3/2} - h_2^{3/2})$.

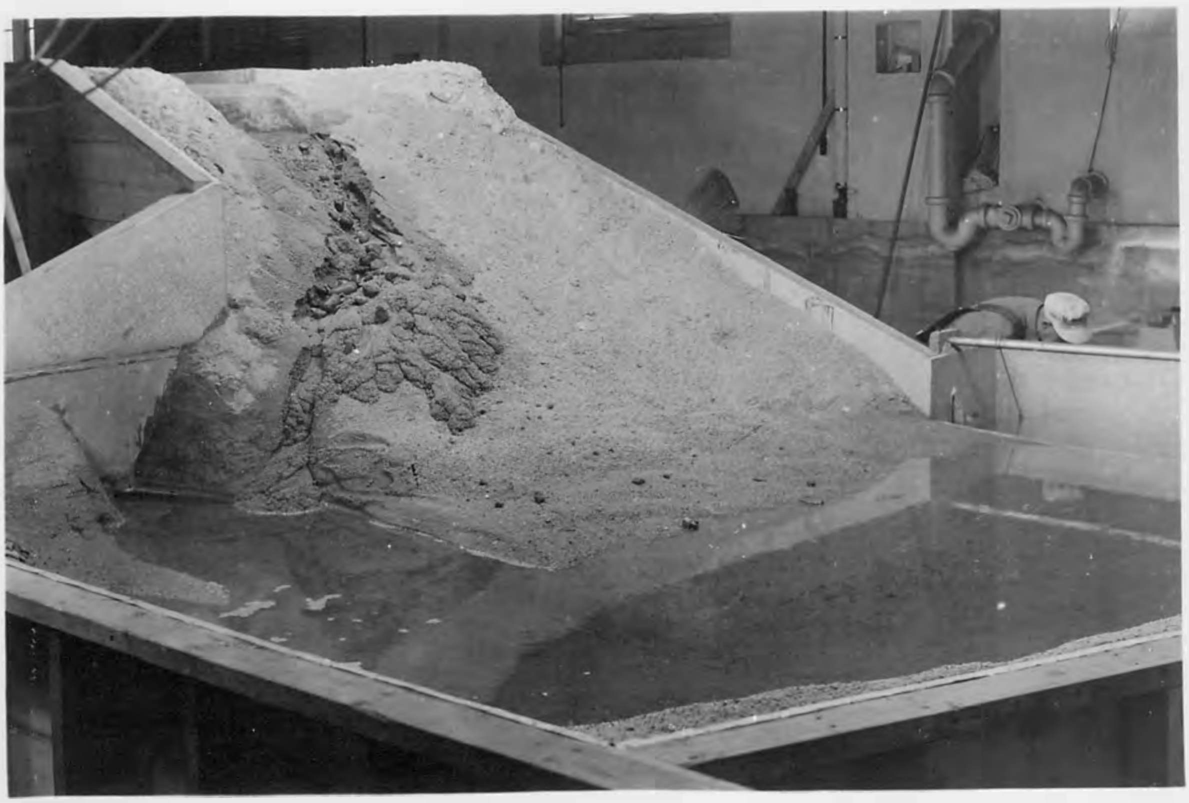
- • Stewart Mountain Dam Scale 1:50
- x Bull Lake Dam Scale 1:30
- ⊙ Wheeler Dam Scale 1:36
- + Caddoa Dam Scale 1:36
- ⊕ R. E. Horton's Experiments
- ▲ Granby Dam Scale 1:48

COEFFICIENT OF DISCHARGE
RADIAL GATES

4-2-42 R. R. P.

X-D-441

DOWNSTREAM END OF SPILLWAY AND OUTLET WORKS.



EROSION CAUSED BY MAXIMUM FLOW THROUGH OUTLET AND LEAKAGE THROUGH SPILLWAY GATES.

ORIGINAL DESIGN

SECOND STEP IN EROSION CAUSED BY GRADUALLY OPENING SPILLWAY GATES.
MAXIMUM FLOW THROUGH OUTLET.

EROSION CAUSED BY MAXIMUM FLOW THROUGH SPILLWAY OF 12,000 SECOND-FEET.
MAXIMUM FLOW THROUGH OUTLET.

ORIGINAL DESIGN

EROSION CAUSED BY MAXIMUM FLOW THROUGH SPILLWAY AND OUTLET.

ORIGINAL DESIGN

DOWNSTREAM END OF SPILLWAY AND OUTLET WORKS.

EROSION CAUSED BY MAXIMUM FLOW THROUGH OUTLET AND LEAKAGE THROUGH SPILLWAY GATES.

ORIGINAL DESIGN WITH CORRECTED TOPOGRAPHY

SECOND STEP IN EROSION CAUSED BY GRADUALLY OPENING SPILLWAY GATES.
MAXIMUM FLOW THROUGH OUTLET.

THIRD STEP IN EROSION CAUSED BY GRADUALLY OPENING SPILLWAY GATES.
MAXIMUM FLOW THROUGH OUTLET.

ORIGINAL DESIGN WITH CORRECTED TOPOGRAPHY

EROSION CAUSED BY MAXIMUM FLOW THROUGH SPILLWAY OF 12,000 SECOND-FEET.
MAXIMUM FLOW THROUGH OUTLET.

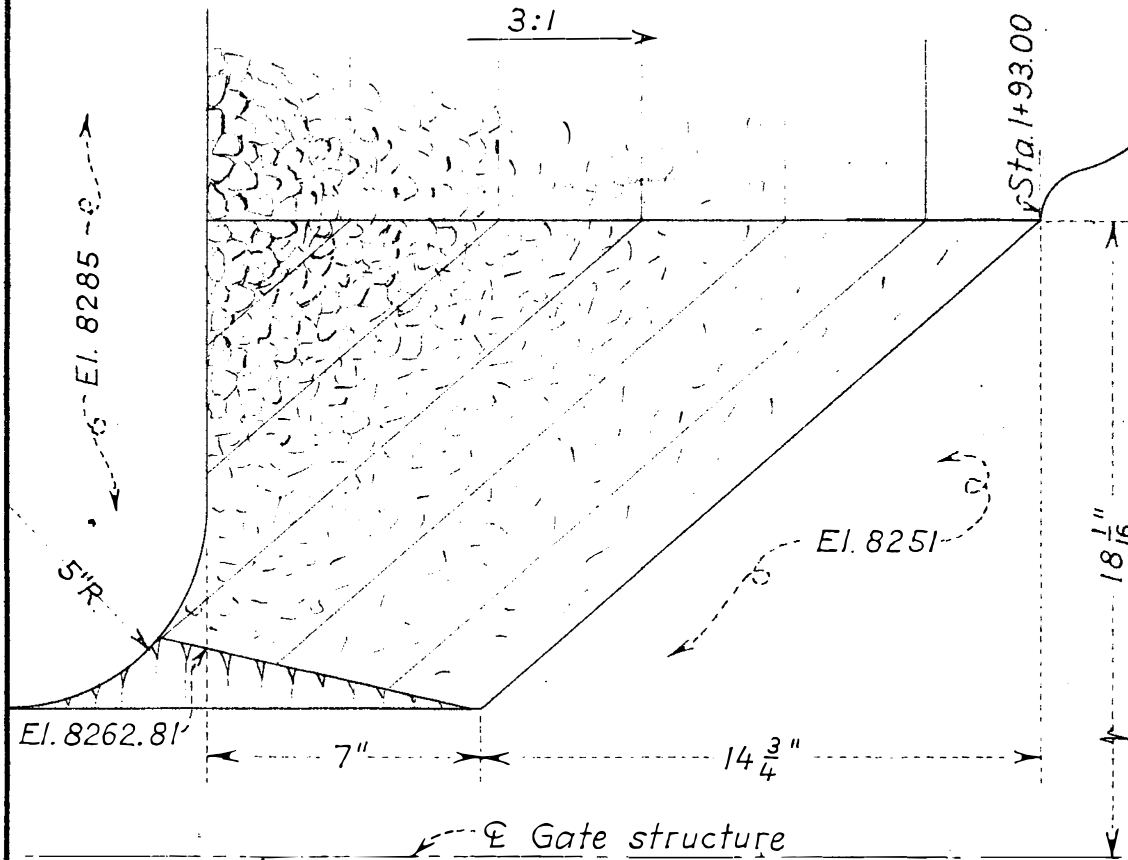
EROSION CAUSED BY GRADUALLY OPENING SPILLWAY GATES TO MAXIMUM DISCHARGE.

ORIGINAL DESIGN WITH CORRECTED TOPOGRAPHY

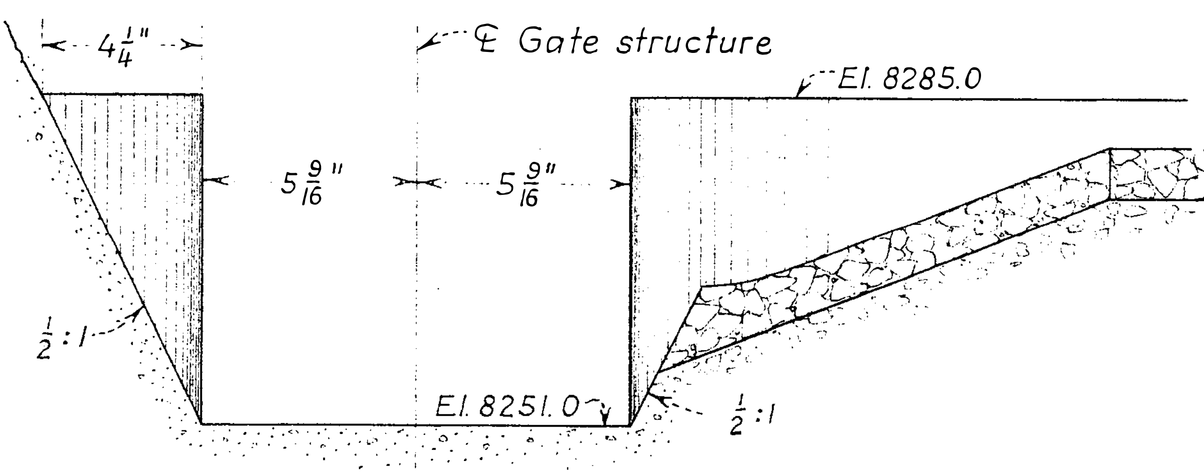
EROSION CAUSED BY MAXIMUM FLOW THROUGH SPILLWAY WHEN GATES ARE OPENED RAPIDLY. MAXIMUM FLOW THROUGH OUTLET.

EROSION CAUSED BY MAXIMUM FLOW THROUGH SPILLWAY WHEN GATES ARE OPENED SLOWLY. MAXIMUM FLOW THROUGH OUTLET.

ORIGINAL DESIGN WITH CORRECTED TOPOGRAPHY



PLAN VIEW OF RIGHT HALF OF APPROACH

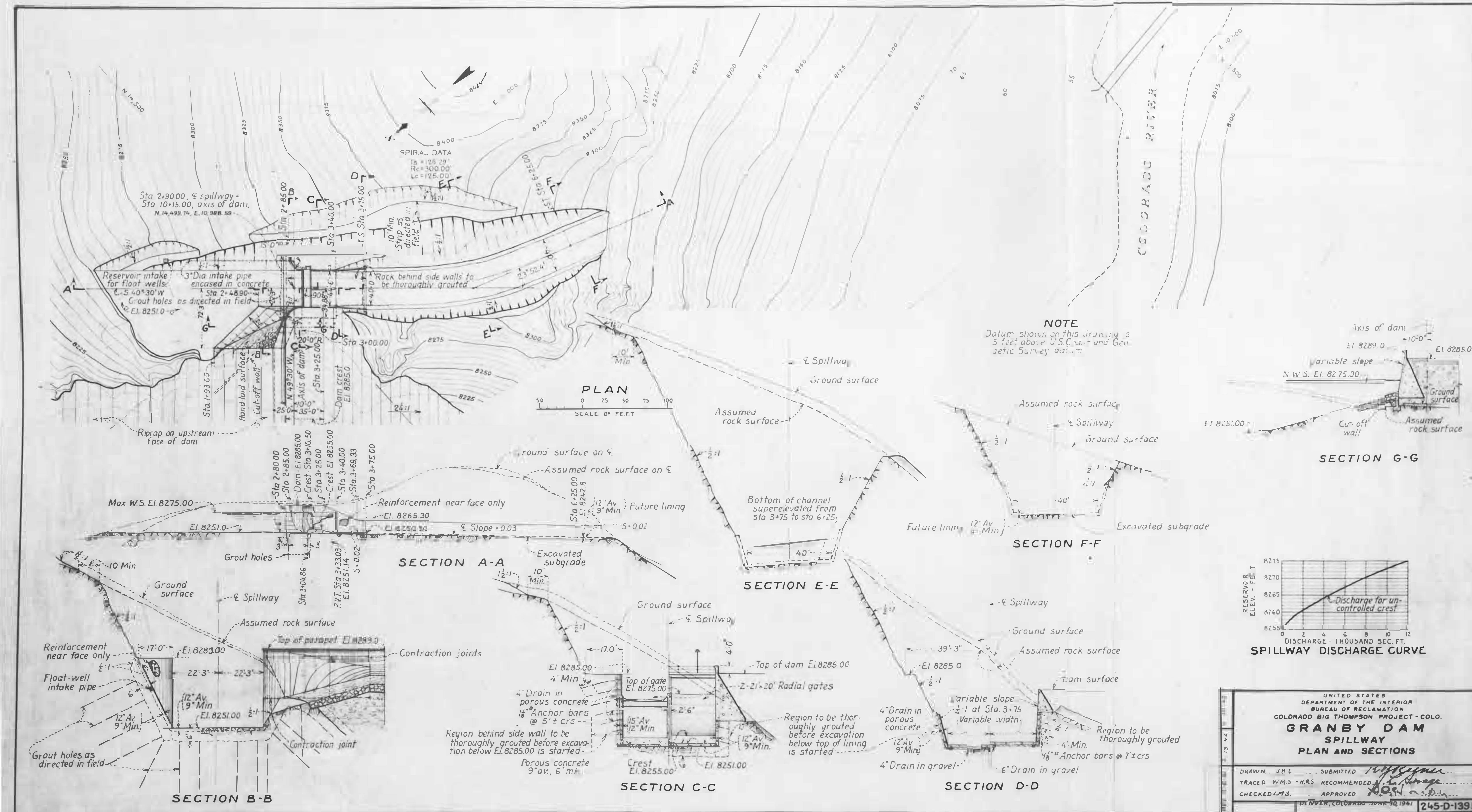


SECTION THRU APPROACH

GRANBY DAM

MODEL ENTRANCE APPROACH—FINAL DESIGN

1:48 MODEL OF SPILLWAY


DRAWING No.
SPIRAL DATA
Ts = 126.29'
Rc = 300.00'
Lc = 125.00'
Sta 2+90.00, ℄ spillway = Sta 10+15.00, axis of dam, N.14,499.74, E.10,988.59
Reservoir intake for float wells
3" Dia intake pipe encased in concrete
Grout holes as directed in field
Rock behind side walls to be thoroughly grouted
10 Min. Strip as directed in field
Riprap on upstream face of dam
Hand-laid surface
Cut-off wall
Axis of dam
Dam crest El. 8285.0
COLORADO RIVER
PLAN
SCALE OF FEET
NOTE
Datum shown on this drawing is 3 feet above U.S. Coast and Geodetic Survey datum
Max W.S. El. 8275.00
Reinforcement near face only
El. 8265.30
El. 8251.0
℄ Slope = 0.03
Ground surface on ℄
Assumed rock surface on ℄
Future lining
Excavated subgrade
Grout holes
SECTION A-A
Ground surface
℄ Spillway
Assumed rock surface
Top of parapet El. 8289.0
Contraction joints
Float-well intake pipe
Grout holes as directed in field
Contraction joint
SECTION B-B
Top of dam El. 8285.00
Top of gate El. 8275.00
2-21'×20' Radial gates
4" Drain in porous concrete
1 1/8" Ø Anchor bars @ 5' ± crs
Region behind side wall to be thoroughly grouted before excavation below El. 8285.00 is started
Porous concrete 9" av., 6" min.
Crest El. 8255.00
El. 8251.00
Region to be thoroughly grouted before excavation below top of lining is started
SECTION C-C
Bottom of channel superelevated from sta 3+75 to sta 6+25
SECTION E-E
Variable slope 1/2:1 at Sta. 3+75
Variable width
Dam surface
Region to be thoroughly grouted
4" Drain in gravel
6" Drain in gravel
1 1/8" Ø Anchor bars @ 7' ± crs
SECTION D-D
Assumed rock surface
Ground surface
Future lining
Excavated subgrade
SECTION F-F
Axis of dam
El. 8289.0
El. 8285.0
Variable slope
N.W.S. El. 8275.00
El. 8251.00
Cut-off wall
Assumed rock surface
SECTION G-G
RESERVOIR ELEV. - FEET
DISCHARGE - THOUSAND SEC. FT.
Discharge for uncontrolled crest
SPILLWAY DISCHARGE CURVE
UNITED STATES
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COLORADO BIG THOMPSON PROJECT - COLO.
GRANBY DAM
SPILLWAY
PLAN AND SECTIONS
DRAWN J.H.L.
TRACED W.M.S. - H.R.S.
CHECKED L.M.S.
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO JUNE 10, 1941
245-D-1391