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HYDRAULIC LABORATORY REPORT NO. 43

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HYDRAULIC CHECK OF THE PROPOSED CRANE PRAIRIE DAM OUTLET WORKS STILLING BASIN

By

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Denver, Colorado

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MEMORANDUM TO ENGINEER J. E. WARNOCK
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Subject: Hydraulic check of the proposed Crane Prairie Dam Outlet Works Stilling Basin.

1. Crest elevation of the hydraulic hump. The crest elevation must be determined to satisfy three conditions: (a) to properly spread the jet from the tunnels for all combinations of discharge, (b) to force the jump to form downstream from the tunnel exits for all combinations of discharge, and (c) to form a quiet stable hydraulic jump in the stilling basin.

From a series of tests for the Bull Lake Outlet Works Stilling Basin, for which the best dimensions were determined, conditions (a) and (b) were satisfied when the hump crest elevation was about equal to the maximum water surface elevation at the tunnel exits. Velocity at tunnel exits, distance between tunnel exits and crest of hump and amount of flare of side walls from tunnel exits also influence the proper hump crest elevation; but these will be considered later. These same tests indicated that a good stable jump formed in the stilling basin when the mean water surface elevation over the hump crest was equal to or greater than the tailwater elevation below the jump.

When the mean water surface elevation over the hump is considerably less than the tailwater elevation the jump forms too near the hump crest so that the jet maintains its horizontal direction and remains near the surface through the stilling basin. For intermediate crest water surface-tailwater relationships, the jet fluctuates alternately from the bottom to the top of the pool, resulting in very unstable jump conditions.

For a tunnel exit velocity of 31 feet per second and a maximum discharge of 1800 second-feet, the mean depth at the tunnel exit is 4.5 feet and the water-surface elevation is 4422.2, which makes the proposed crest 1.2 feet too low. When the tunnel exit velocity is reduced by an amount whose velocity head is equal to the difference in elevations at the tunnel invert and the hump crest, the velocity over the hump crest is determined. This method checked measurements for the Bull Lake hump. The hump crest velocity is $\sqrt{(31)^2 - 64.4 \times 3.3} = 27.4$ feet per second; the corresponding mean depth over the crest is 3.29 feet; and the mean elevation of water surface is 4424.29. The proposed crest is 1.7 feet too low to satisfy condition (c). From these arguments, raising the crest to elevation 4422.50 would result in a more satisfactory design.

2. Flare of chute side walls from tunnel exits to hump crest. Proper flaring of these walls is attained when there is a good spreading of the jets at the hump crest. The most adverse condition for spreading is given by one tunnel only operating at maximum capacity. A good measure of the amount of spreading is the deflection angle produced by a particle of water traveling in a straight line from the inside edge of the tunnel exit to the chute wall at the hump crest on the same side as the tunnel not operating. This angle is 27°-42' for the Bull Lake chute and 30°-12' for the proposed design. Since the deflection angle for satisfactory operation increases for decreasing velocities and since the Bull Lake tunnel exit velocity is about 40 feet per second compared to 31 feet per second for the proposed design, 30°-12' is probably not excessive for the proposed design.

3. Upstream slope of the hump. Effective spreading of the jet is increased by increasing the upstream hump slope. If this slope is made too great, however, the jet will spring from the downstream slope of the hump and the distribution of flow over the hump crest will become too uneven.

The satisfactory upstream hump slope for Bull Lake is 3.08:1. With the lower velocity in the proposed design the 4:1 slope will probably be satisfactory. A 3:1 slope will also be satisfactory and will result in a more even flow distribution over the crest.

4. Distance from tunnel exits to hump crest. This distance is fixed when the proper hump crest elevation, hump upstream slope and chute flare are determined. The 18'-3" length of the proposed design is satisfactory since the upstream hump slope can be increased to give the suggested 1.5 feet increase in hump crest elevation.

5. The hump trajectory. Derivation of the theoretical equation for the hump trajectory gives:

$$y = x \tan \phi + \frac{g}{2 V_o^2 \cos^2 \phi} x^2 \text{----} \quad (1)$$

where x is the horizontal coordinate, y the vertical coordinate, ϕ the slope angle of the velocity direction at the beginning of the trajectory, V_o the mean cross-sectional velocity for maximum discharge at the beginning of the trajectory and g the acceleration of gravity.

A trajectory designed on the bases of the mean velocity will be too steep for the mass of water flowing in the area of maximum velocity, as was verified by the Vallecito spillway tests. For this reason, to prevent any disruption of the jet, the trajectory should be designed for at least the maximum velocity in the tranverse section at the beginning of the trajectory. Assuming a maximum velocity equal to 120 percent of the mean velocity, the trajectory equation becomes:

$$y = x \tan \phi + \frac{g}{2.88 V_o^2 \cos^2 \phi} x^2 \quad (2)$$

Some present designers for the sake of safety use half the value of g in the original equation which then becomes:

$$y = x \tan \phi + \frac{g}{4 V_o^2 \cos^2 \phi} x^2 \quad (3)$$

This more conservative formula becomes less conservative when air is entrained in the flow as was shown by field measurements on the Kittitas Chute, Yakima Project. When a mass of water-air mixture passes over a convex vertical curve at high velocity, the reduction of internal pressure within the mass due to centrifugal action results in an expansion of the air bubbles within the mass, effectively reducing the action of gravity, which requires flatter slopes to prevent disruption of the jet as was experienced in the Kittitas Chute.

In figure 1, trajectories for equations (1) and (3) are plotted with the P.C. of the upstream hump slope as the beginning of the trajectory and an initial velocity of 26.1 feet per second parallel to the 3:1 upstream slope. The chute floor should follow the lower equation (3) trajectory if a smooth jet is required over the hump. The trajectory for equation (1) based on the mean cross-sectional velocity, lies above the proposed trajectory, which, according to previous design methods suggests a region of negative pressure, and a tendency for the jet to spring clear of the bottom.

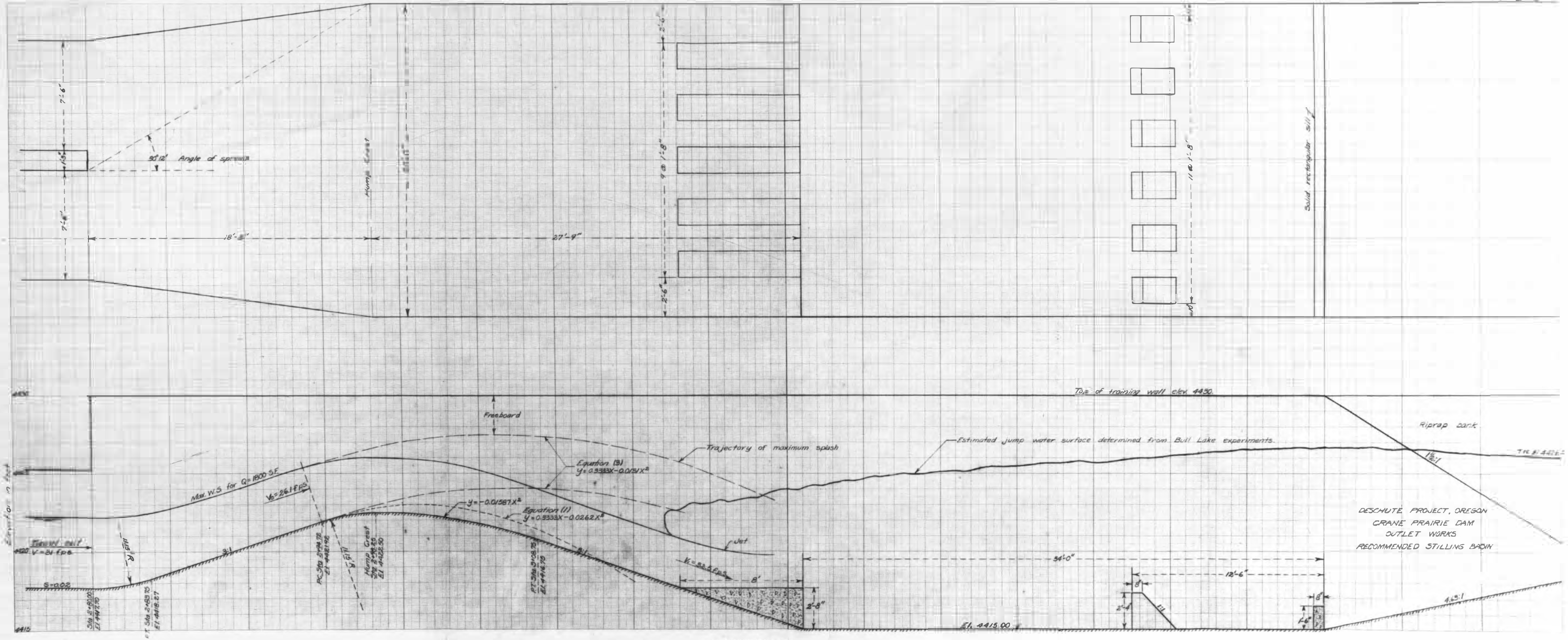
The jet did not spring from the bottom for the recommended Bull Lake design, although the jet velocity was somewhat higher than for the Crane Prairie design. There are two factors which prevent the jet from springing clear of an apparently too steep trajectory: (a) the trajectories of layers of water near the bottom are much steeper than that based on the mean velocity; and (b) the jet is held to the floor due to insufficient aeration.

When the equation (3) trajectory is plotted from the jet water surface, this curve will approximately represent the path of maximum splash. With the proposed design, there will probably be considerable disruption of the jet on its surface, similar to Kittitas; but this will have no harmful effect since there is excess freeboard and the jet splash will enter the pool at the beginning of the jump. The proposed downstream hump profile is satisfactory except that the equation of the parabola is changed slightly to $y = -0.01587\ x^2$ so that the 3:1 slope will end at Station 3+24.00.

6. The stilling basin. The stilling basin will be designed by the use of the attached diagram; office memorandum dated June 8, 1938; subject: Stilling basin design for rectangular spillway channels. Hydraulic experiments have shown the apron block and end sill type of basin to be superior to the Rehbock type.

A conservative value of V_1 is 33.7 feet per second and d_1 is 2.67 feet. From the diagram, d_2 is 12.6 feet and d'_2 is 10.7 feet. With the maximum tailwater at elevation 4426, the proposed floor can be raised two feet to elevation 4415.00. The basin length is given as 37.8 feet. With the 17 feet long end transition a 34-foot length is sufficient. The diagram gives the following block and sill dimensions: $h_1 = 2.67' = 2'$-8": $h_2 = 2.3' = 2'$-4": $h_3 = 1.6' = 1'$-6"; $a = 12.6' = 12'$-6". For economical and structural reasons, the small end sill should be rectangular in cross-section. The recommended design is shown in figure 1. The stilling basin dimensions compare favorably with those of the adopted Bull Lake design.

FIGURE



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