UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

DESIGN OF SMALL DAMS

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width then becomes a matter of economics as well as hydraulic performance.

(4) *Alternative Low Froude Number Stilling Basins.*—Type IV basins are fairly effective at low Froude number flows for small canals and for structures with small unit discharges. However, recent model tests have developed designs quite different from the type IV basin design, even though the type IV basin design was included in the initial tests.

Palmetto Bend Dam stilling basin [22] is an example of a low Froude number structure, modeled in the Bureau of Reclamation Hydraulics Laboratory, whose recommended design is quite different from type IV design. The type IV design has large deflector blocks, similar to but larger than chute blocks, and an optional solid end sill; the Palmetto Bend design has no chute blocks, but has large baffle piers and a dentated end sill.

The foregoing generalized designs have not been suitable for some Bureau applications, and the increased use of low Froude number stilling basins has created a need for additional data on this type of design. A study was initiated to develop generalized criteria for the design of low Froude number hydraulic-jump stilling basins. The criteria and guidelines from previous studies were combined with the results of this study to formulate the design guidelines recommended for low Froude number stilling basins [23]. However, it should be noted that a hydraulic-jump stilling basin is not an efficient energy dissipator at low Froude numbers; that is, the efficiency of a hydraulic-jump basin is less than 50 percent in this Froude number range. Alternative energy dissipators, such as the baffled apron chute or spillway, should be considered for these conditions.

The recommended design has chute blocks, baffle piers, and a dentated end sill. All design data are presented on figure 9-40. The length is rather short, approximately three times d_2 (the conjugate depth after the jump). The size and spacing of the chute blocks and baffle piers are a function of d_1 (incoming depth) and the Froude number. The dentated end sill is proportioned according to d_2 and the Froude number. The end sill is placed at or near the downstream end of the stilling basin. Erosion tests were not included in the development of this basin. Observations of flow patterns near the invert downstream from the basin indicated that no erosion problem should exist. However, if hydraulic model tests are performed to confirm a design based on these criteria, erosion tests should be included. Tests should be made over a full range of discharges to determine whether abrasive materials will move upstream into the basin and to determine the erosion potential downstream from the basin. If the inflow velocity is greater than 50 ft/s, hydraulic model studies should be performed.

(5) *Basins for Froude Numbers Higher Than 4.5.*—For these basins, a true hydraulic jump will form. The elements of the jump will vary according to the Foude number, as shown on figure B-15. The installation of accessory devices such as blocks, baffles, and sills along the floor of the basin produce a stabilizing effect on the jump, which permits shortening the basin and provides a safety factor against sweepout caused by inadequate tailwater depth.

The basin shown on figure 9-41, which is designated a type III basin, can be adopted where incoming velocities do not exceed 60 ft/s. The type III basin uses chute blocks, impact baffle blocks, and an end sill to shorten the jump length and to dissipate the high-velocity flow within the shortened basin length. This basin relies on dissipation of energy by the impact blocks and on the turbulence of the jump phenomena for its effectiveness. Because of the large impact forces to which the baffles are subjected by the impingement of high incoming velocities and because of the possibility of cavitation along the surfaces of the blocks and floor, the use of this basin must be limited to heads where the velocity does not exceed 60 ft/s.

Cognizance must be taken of the added loads placed on the structure floor by the dynamic force brought against the upstream face of the baffle blocks. This dynamic force will approximate that of a jet impinging upon a plane normal to the direction of flow. The force, in pounds, may be expressed by the formula:

$$\text{Force} = 2wA(d_1+h_{v_1}) \qquad (24)$$

where:

w = unit weight of water, in pounds per cubic foot,
A = area of the upstream face of the block, in square feet, and
$(d_1+h_{v_1})$ = the specific energy of the flow entering the basin, in feet.

Negative pressure on the back face of the blocks will further increase the total load. However, because the baffle blocks are placed a distance equal to $0.8d_2$ beyond the start of the jump, there will be some cushioning effect by the time the incoming jet reaches the blocks, and the force will be less than that indicated by the above equation. If the full force computed by equation (24) is used, the negative pressure force may be neglected.

Where incoming velocities exceed 60 ft/s, or where impact baffle blocks are not used, the type II basin (fig. 9-42) may be adopted. Because the dissipation is accomplished primarily by hydraulic-jump action, the basin length will be greater than that indicated for the type III basin. However, the chute blocks and dentated end sill will still effectively reduce the length. Because of the reduced margin of safety against sweepout, the water depth in the basin should be about 5 percent greater than the computed conjugate depth.

(c) *Rectangular Versus Trapezoidal Stilling Basin.*—The use of a trapezoidal stilling basin instead of a rectangular basin may often be proposed where economy favors sloped side lining over vertical wall construction. Model tests have shown, however, that the hydraulic-jump action in a trapezoidal basin is much less complete and less stable than it is in the rectangular basin. In a trapezoidal basin, the water in the triangular areas along the sides of the basin adjacent to the jump does not oppose the incoming high-velocity jet. The jump, which tends to occur vertically, cannot spread sufficiently to occupy the side areas. Consequently, the jump will form only in the central portion of the basin, while areas along the outside will be occupied by upstream-moving flows that ravel off the jump or come from the lower end of the basin. The eddy or horizontal roller action resulting from this phenomenon tends to interfere and interrupt the jump action to the extent that there is incomplete dissipation of the energy and severe scouring can occur beyond the basin. For good hydraulic performance, the sidewalls of a stilling basin should be vertical or as close to vertical as practicable.

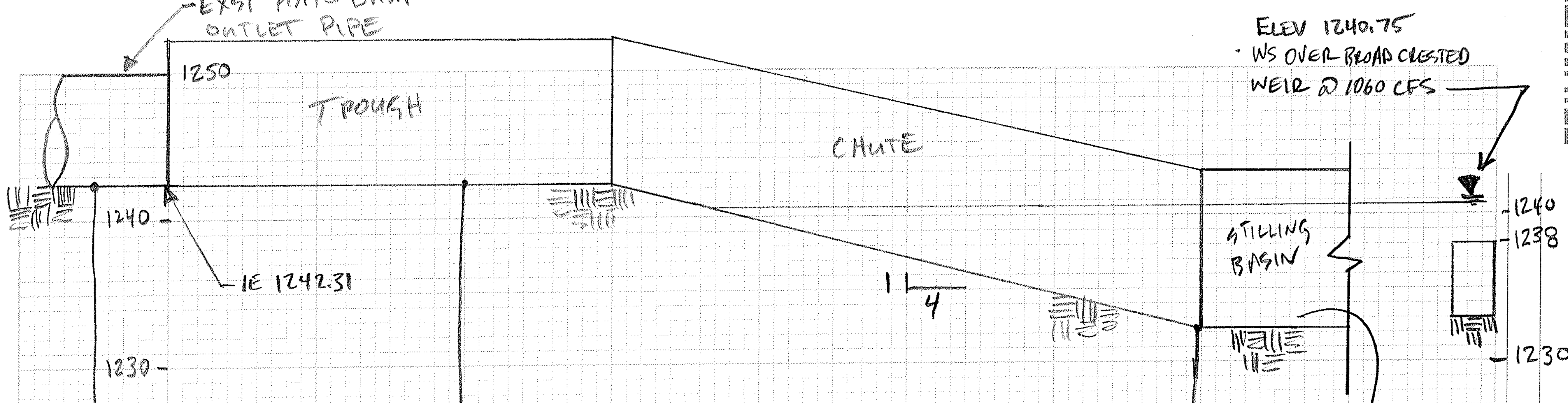
(d) *Basin Depths Versus Hydraulic Heads.*—The nomograph on figure 9-43 can help determine approximate basin depths for various basin widths and for various differences between reservoir and tailwater levels. Plots are shown for the condition of no loss of head to the upstream end of the stilling basin, and for 10, 20, and 30 percent loss as scales A, B, C, and D, respectively. The required conjugate depths, d_2, will depend on the specific energy available at the entrance of the basin, as determined by the procedure discussed in section 9.18. Where the specific energy is known, the head loss in the channel upstream can be related to the velocity head, the percentage loss can be determined, and the approximate conjugate depth can be read for the nomograph. Where head losses have not been computed, a quick approximation of the head losses can be obtained from figure B-5. Where only a rough determination of basin depths is needed, the choice of the loss to be applied for various spillway designs may be generalized as follows:

(1) For a design of an overflow spillway where the basin is directly downstream from the crest, or where the chute is not longer than the hydraulic head, consider no loss of head.
(2) For a design of a channel spillway where the channel length is between one and five times the hydraulic head, consider 10 percent loss of head.
(3) For a design of a spillway where the channel length exceeds five times the hydraulic head, consider 20 percent loss of head.

The nomograph on figure 9-43 gives values of the conjugate depth of the hydraulic jump. Tailwater depths for the various types of basin described should be increased as noted earlier in this section.

(e) *Tailwater Considerations.*—Determination of the tailwater rating curve, which gives the stage-discharge relationship of the natural stream below the dam, is discussed in appendix B, part B. Tailwater rating curves for the regime of river below a dam are fixed by the natural conditions along the stream and ordinarily cannot be altered by the spillway design or by the release characteristics. As discussed in section 9.7(d), the retrogression or aggradation of the river below the dam, which will affect the ultimate stage-discharge conditions, must be recognized in selecting the tailwater rating curve to be used for stilling basin design. Usually, river flows that approach the maximum design discharges do not occur, and an estimate of the tailwater rating curve must either be extrapolated from known conditions or computed on a basis of assumed or empirical criteria. Thus, the tailwater rating curve is, at best, only approximate, and safety factors must be included in the design to compensate for variations in tailwater.

For a jump-type stilling basin, downstream water



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INPUT

Q = 1060 CFS
ϕ = 7.25 FT
N = 0.014
S = 0.00503

OUTPUT

d = 7.25 FT
V = 25.7 FT/SEC

INPUT

Q = 1060 CFS
W = 15 FT
N = 0.012
S = 1"/20FT = 0.0042

OUTPUT

d = 4.44 FT
V = 15.9 FT/SEC

INPUT

Q = 1060 CFS
W = 40 FT
N = 0.012
S = 1/4 = 0.25

OUTPUT

d = 0.61 FT
V = 43.6 FT/SEC

$\therefore$ FROUDE # $\Rightarrow F = \frac{V}{\sqrt{g d_1}}$

$F = \frac{43.6}{\sqrt{32.2(0.61)}} =$

$F = 9.84$

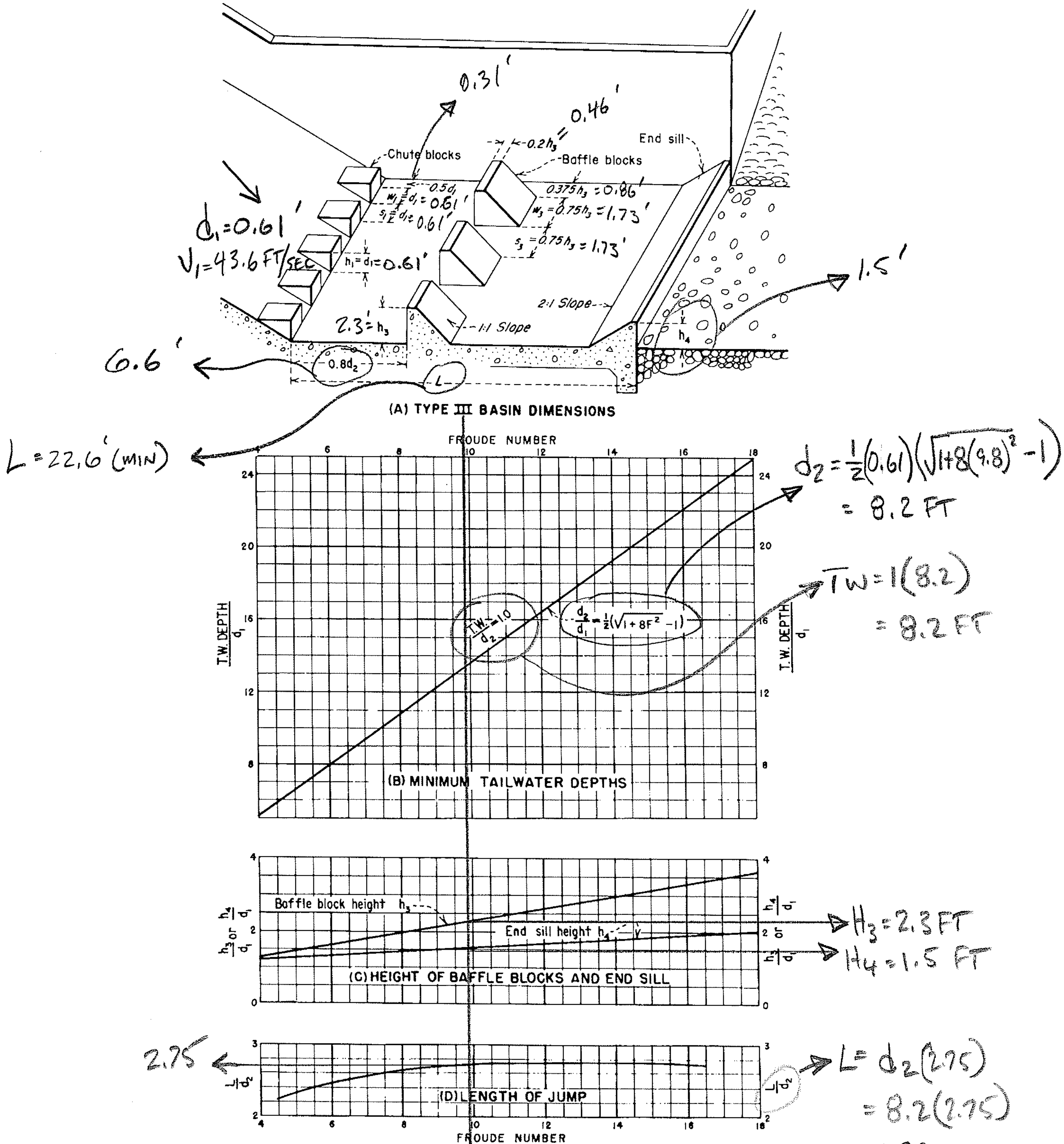

Figure 9-41.—Stilling basin characteristics for Froude numbers above 4.5 where incoming velocity, $V_1 \leq 60$ ft/s. 288–D–2426.

F = 9.8

43.6 < 60 ✓