TEST RESULTS

The results of the tests made to determine the dimensions of the straight drop spillway stilling basin will be presented separately for each element comprising the basin. The order of presentation is not the order in which the tests were conducted. In fact, it was necessary to study some elements several times because a change in one element would affect the performance of other elements, and the best result could only be obtained after each element had its optimum dimensions.

Length of Basin

It was recognized before the tests were begun that the point at which the nappe hit the stilling basin floor would provide one of the dimensions for the determination of the basin length. Other dimensions determining the basin length are the distance from the nappe to the floor blocks and the distance from the floor blocks to the end of the basin. Each of these dimensions will be discussed in turn.

Nappe Trajectory

The equation first used during these studies to give the trajectory of the upper surface of the free-falling nappe is

$$\frac{y_n}{H} = 0.46 - 0.105 \left[3 \left(\frac{x_n}{H} \right)^2 + 2 \left(\frac{x_n}{H} \right) \right]$$

where y_n is the vertical distance, x_n is the horizontal distance from the crest to the upper surface of the nappe, and H is the total head. This equation was derived from data presented by Dr. A. T. Ippen [5] for the free overfall, since the straight drop spillway is assumed to have the approach channel level with the spillway crest.

This equation proved satisfactory until tests were run with the tailwater level close to the spillway crest. For these tests the nappe did not fall freely but was supported by the high tailwater. The result was that the nappe hit the stream bed downstream of the stilling basin and scoured a deep hole there. The fact that greater scour was obtained with a higher tailwater level had an important effect on the stilling basin design. Although this discovery is contrary to the widely held opinion that higher tailwater will cause less scour to occur, it is an entirely logical finding. The water in the free-falling nappe is assumed to have a constant horizontal velocity and a vertical velocity accelerating under the effect of gravity. After the free-falling nappe plunges into the tailwater, gravity is no longer effective and the submerged nappe will continue in the direction the free-falling nappe was traveling when it entered the tailwater. Near the crest the upper surface of the free-falling nappe trajectory has a relatively flat slope, and if the tailwater level is also close to the crest, the submerged nappe will continue on this flat slope. The result is, of course, that the submerged nappe trajectory is well downstream of the free-falling nappe trajectory when the tailwater level is high.

One qualification to the statement regarding the plunging nappe should be made. When the tailwater level is considerably above the crest of the spillway, the nappe does not plunge through the tailwater but "floats" on or close to the surface of the tailwater. For this condition, the nappe does not attack the bed downstream from the stilling basin. During the tests it was noticed that the "surface nappe" occurred when the depth of the tailwater above the spillway crest level exceeded two-thirds the critical depth approximately. Therefore, it is concluded that the effect of high tailwater levels on the position of the nappe need not be considered in the determination of the stilling basin length when the tailwater level exceeds the spillway crest elevation plus two-thirds the critical depth, but the effect of tailwater on the nappe trajectory must be considered for tailwater elevations lower than the spillway crest elevation plus two-thirds the critical depth. In other words, the maximum tailwater level that will affect the stilling basin length is that level which is two-thirds the critical depth above the spillway crest level.

After discovering that the tailwater level influenced the nappe trajectory, tests were made considering that the nappe is free-falling to the tailwater level and continues on a tangent beyond that point. These tests resulted in considerably longer basins when the tailwater was high. In fact, the experiments showed that the basins were longer than necessary so they were shortened successively until they were so short that their performance became poor. As a result of these tests, the optimum trajectory of the upper nappe surface for use in determining one of the elements making up the basin length was found to be midway between the free-falling and the submerged trajectories.

This mean trajectory was used for all subsequent tests and was found to give entirely satisfactory results. It is proposed only for use in determining the length of the straight drop spillway stilling basin and should not be used for other purposes until it is confirmed for such use.

The equation of the upper surface of the free-falling nappe proposed for use is

$$\frac{x_n}{d_c} = -\ 0.406 + \sqrt{3.195 - 4.386\,\frac{y_n}{d_c}} \tag{1}$$

This equation is a rearrangement and a substitution of $3d_c/2$ for H in the general equation for free-falling nappes presented by Blaisdell [6]. It applies to the free overfall only.

At the point where the upper surface of the free-falling nappe strikes the stilling basin floor, Eq. (1) becomes

$$\frac{x_F}{d_c} = -\ 0.406 + \sqrt{3.195 - 4.368\,\frac{y}{d_c}} \tag{2}$$

where x_F is the horizontal distance from the crest to the upper surface of the free-falling nappe at the elevation of the stilling basin floor.

The equation for the upper surface of the submerged nappe trajectory above the tailwater level is the same as that for the free-falling nappe. The point at which the upper nappe plunges into the tailwater is

$$\frac{x_t}{d_c} = -\ 0.406 + \sqrt{3.195 - 4.386\,\frac{y_t}{d_c}} \tag{3}$$

where x_t is the horizontal distance from the crest to the point at which the surface of the upper nappe plunges into the tailwater and y_t is the vertical distance from the crest to the tailwater surface. It is necessary to keep the signs correct, remembering that y_t is positive above crest elevation and negative below. This is illustrated in the definition sketch of Fig. 2. The equation of the trajectory of the upper nappe surface below tailwater level is

$$\frac{x_{ns}}{d_c} = \frac{0.691 + 0.228\ (x_t/d_c)^2 - (y_n/d_c)}{0.185 + 0.456\ (x_t/d_c)} \tag{4}$$

where x_{ns} is the horizontal distance from the crest to the upper surface of the submerged nappe. Equation (4) was obtained by considering that the portion of the nappe trajectory above the tailwater level has the same equation as does the free nappe trajectory, while below the tailwater level the nappe trajectory has a slope equal to

$$\frac{d\ (y_t/d_c)}{d\ (x_t/d_c)} = -\ 0.185 - 0.456\ \frac{x_t}{d_c} \tag{5}$$

Equation (5) can be obtained by rearranging and differentiating Eq. (3).

At the point where the upper surface of the submerged nappe trajectory strikes the stilling basin floor, Eq. (4) becomes

$$\frac{x_T}{d_c} = \frac{0.691 + 0.228\ (x_t/d_c)^2 - (y/d_c)}{0.185 + 0.456\ (x_t/d_c)} \tag{6}$$

The distance from the crest at which the average of the upper surfaces of the free and submerged nappes strikes the floor x_a is used to determine part of the stilling basin length. The equation for x_a is

$$x_a = \frac{x_F + x_T}{2} \tag{7}$$

Values of x_a have been computed for a wide range of conditions. These results are presented graphically in Fig. 2.

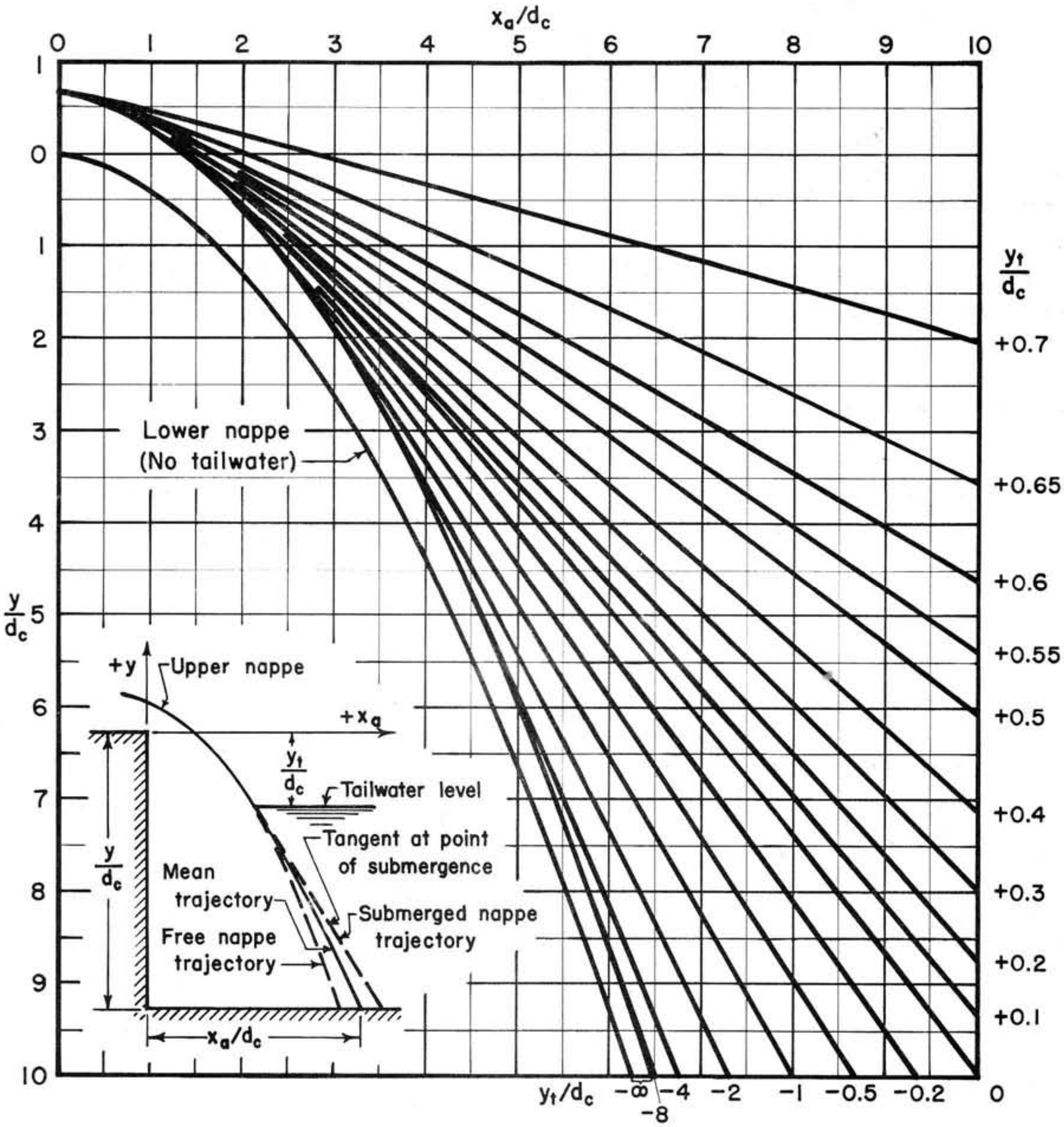

Fig. 2 – Design Chart for Determination of x_a