U. S. Dept. of Agriculture
Soil Conservation Service
Engineering Division
Design Branch

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DESIGN NOTE NO. 1*

Subject: Scour Protection at Base of Risers to Drop Inlet Spillways

Damaging scour has occurred at the base of several risers to drop inlet spillways. It has been associated with flow into the riser through orifices, open sluice gates, or construction diversion openings located close to the bottom. In several cases the scour has undermined the riser foundation and caused the riser to settle out of position so that expensive repairs have been required. Aprons or cutoff walls to prevent such scour had not been provided in any of the cases where failure occurred. In one case rock riprap had been provided, but it washed out.

Difficulties have arisen on the more erodible soils such as SM, ML, SP, SW and low plasticity CL. The GW and GP soils should also be considered as vulnerable. Cohesive soils with a moderately high plasticity conceivably could be eroded if the duration of flow through the orifice is for long periods. Such scour is cumulative and it is quite possible that problems will arise on additional existing structures if it becomes necessary to open gates located near the bottom of the riser for extended periods of time.

Protection against scour should be provided where the possibility of damage exists. An apron will provide such protection. Direct experimental or analytical evidence is not available for the design of such an apron. However, guidance is available from the work reported by Mr. Fred W. Blaisdell in a paper "Hood Inlets for Closed Conduit Spillways" published in the Journal of the Hydraulics Division, Proceedings of ASCE, May 1960.

Mr. Blaisdell developed two equations that are useful. The equation for the radius of scour hole at the inlet of the hood inlet spillway is

$$\frac{R}{D} = \left[0.15 + 0.04 \frac{Q}{D^{2.5}}\right] \left(\frac{D}{d}\right)^{0.2} \quad . \quad . \quad . \quad (1)$$

Where: R = radius of the scour hole in feet
D = diameter of pipe in feet
Q = discharge in cfs
d = diameter of mean size of cohesionless sediment in the scour hole in feet.

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The equation for the depth of the scour hole is

$$\frac{S}{D} = \frac{1}{20}\frac{Q}{D^{2.5}} - \frac{d}{D} - 0.075 \quad . \quad . \quad . \quad (2)$$

Where: S = depth of scour hole in feet.

Assume that equation (1) can be used to indicate the length of slab required to prevent scour where the value of y in Fig. 1 is zero.

It is desirable to convert variables from Q to H where H is head of water in feet above the center of the orifice. Accomplish this by use of the standard equation for orifice discharge with a discharge coefficient of 0.6.

For the circular orifice

$$\frac{Q}{D_o^{2.5}} = 3.77\left(\frac{H}{D_o}\right)^{0.5} \quad . \quad . \quad . \quad (3)$$

Where: D_o = diameter of orifice in feet.

Substitute equation (3) into equation (1) and assume D in equation (1) is the diameter of the orifice, D_o, in feet.

$$\frac{R}{D_o} = 0.15\left[1 + \left(\frac{H}{D_o}\right)^{0.5}\right]\left(\frac{D_o}{d}\right)^{0.2} \quad . \quad . \quad (4)$$

Take d = 0.001 ft. (about 0.3 mm) as a mean size for medium sand and substitute into equation (4) to get approximately

$$R = 0.6D_o^{1.2}\left[1 + \left(\frac{H}{D_o}\right)^{0.5}\right] \quad . \quad . \quad . \quad (5)$$

If the invert of the orifice is far enough above the bottom of the riser there will be no scour. Equation (2) is useful in estimating this required distance. Mr. Blaisdell points out that the precision of this equation is low. For this reason and because conservatism is required, the last two terms of the equation are dropped. Substitute equation (3) into equation (2) and apply a conservative factor of safety to obtain

$$S = 0.4\,(HD_o)^{0.5} \quad . \quad . \quad . \quad (6)$$

Where: S = distance (in feet) of bottom of orifice above top of riser floor required to avoid scour.

Let y = actual vertical distance between the invert of the orifice and the top of the riser floor in feet. If $y \geq S$ there should be no scour without an apron and an apron is not needed. For values of $y < S$ assume

$$L = \left(1 - \frac{y}{S}\right)R \qquad . \quad . \quad . \quad (7)$$

Where: L = required length of scour apron in feet.

The above equations are adaptable to a rectangular orifice. The diameter of a circular orifice which has a discharge essentially equal to a rectangular orifice of width, b, and height, h, is

$$D_o = 2 \left(\frac{bh}{\pi}\right)^{0.5} \qquad . \quad . \quad . \quad (8)$$

For a rectangular orifice compute an equivalent D_o from equation (8) and proceed as for a circular orifice of the computed equivalent diameter.

The value of H to be used should be the difference in elevation between the center of the orifice and the stage in the reservoir at which the principal spillway primes to full pipe flow.

Where the orifice is not required for diversion of flow during construction, the least costly solution to this problem will be to place the invert of the orifice as high as possible, up to the value of S required to avoid scour.

The width of the scour apron should be 2L. Where 2L exceeds the out-to-out width of the riser base including footings, the scour apron should extend to the full width of the base of the riser and all the remaining area within a distance L of the vertical centerline of the orifice should be covered with (1) a heavy well-graded riprap having mean size of at least one hundred pound stone over a gravel bed at least 6 inches thick, (2) sack concrete riprap spiked together with reinforcing steel over a 6-inch thick gravel bed, or (3) riprap of precast concrete blocks 1 ft. x 1 ft. x 1 ft. (weight about 145 lbs. each) placed closely together on a gravel bed at least 6 inches thick.

The scour apron should be fastened to the inlet floor with dowels of No. 6 deformed reinforcing steel about 4 feet long on not more than 15-inch centers. These dowels should extend equal distances into the inlet and the scour apron and be bonded to the concrete over their full length except for where they pass through the required joint filler. They should be at mid-depth in the scour apron and located at the specified spacing over its full width.

The joint filler should be from one-half to three-quarters of an inch thick and of durable material.

The scour apron should be at least 8 inches thick.

If a scour apron is required a minimum value of L of two (2) feet or D, whichever is the larger, seems reasonable.

Example:

Given

1. Standard Covered Riser for 30-inch diameter barrel; N_{ih} = 40 ft.; Standard Detailed Drawing No. ES-3030-4020R; sidewall thickness at base of riser = 15 inches; footing projection = 5-3; total out-to-out width of base of riser = 15-6.

2. Rectangular orifice 2 ft. wide × 3 ft. high.

3. Bottom of orifice is 2-0 above invert of inlet, i.e., y = 2.0 ft.

Find - Dimensions of scour apron.

Procedure

Step 1 - Find H. (See Fig. 1.)
$H = 40.0 + 1.25 - 2.0 - 1.5 = 37.75$ ft.

Step 2 - Find equivalent D from equation (8).

$$D_o = 2\left(\frac{bh}{\pi}\right)^{0.5} = 2\left(\frac{2 \times 3}{\pi}\right)^{0.5} = 2.77 \text{ ft.}$$

Step 3 - Compute R from equation (5).

$$R = 0.6D_o^{1.2}\left[1 + \left(\frac{H}{D_o}\right)^{0.5}\right] = 0.6 \times 2.77^{1.2}\left[1 + \left(\frac{37.75}{2.77}\right)^{0.5}\right]$$

$$= 0.6 \times 3.40\ (1 + 3.69) = 9.58$$

Step 4 - Compute S from equation (6).

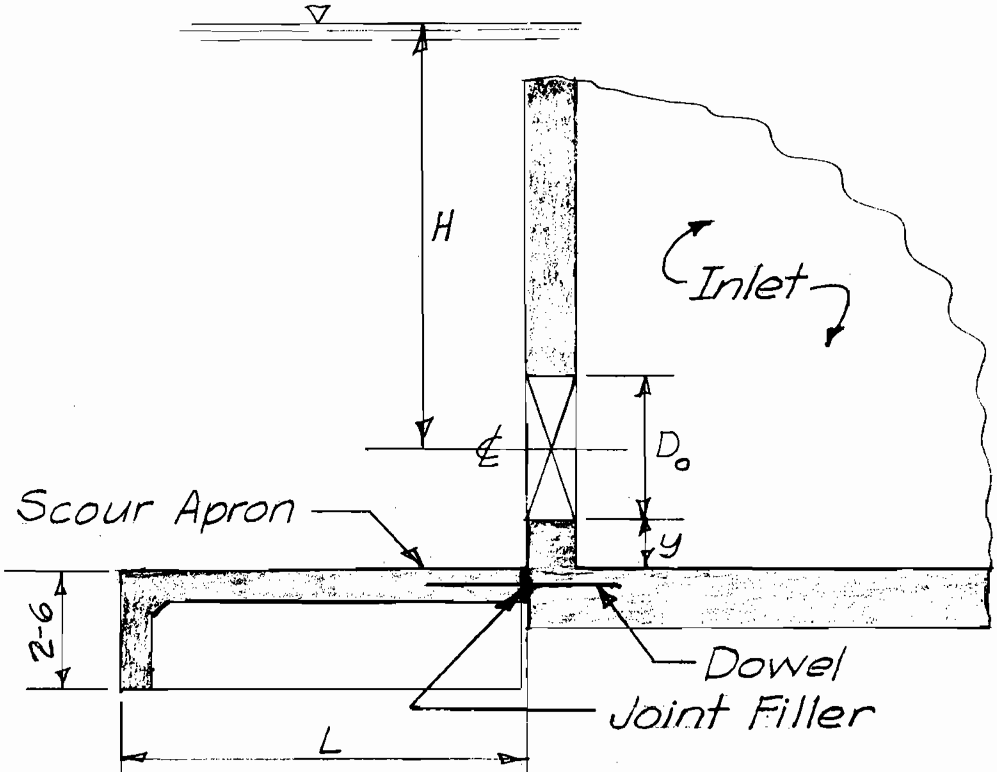
$S = 0.4\ (HD_o)^{0.5} = 0.4\ (37.75\ \times 2.77)^{0.5} = 4.1$ ft.

Step 5 - Compute L from equation (7).

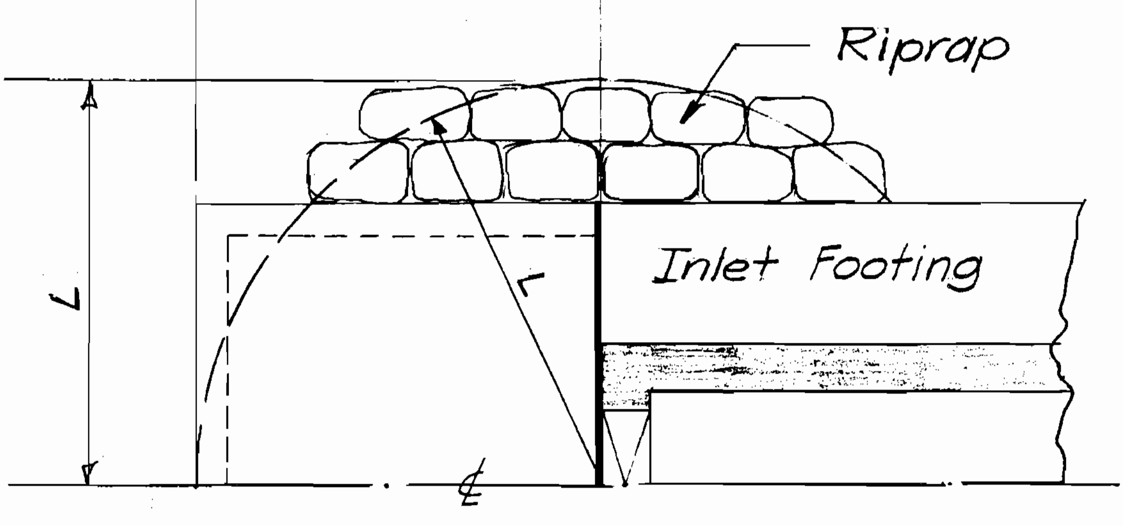
$L = \left(1 - \frac{y}{S}\right) R = \left(1 - \frac{2}{4.1}\right) 9.58 = 4.68$ Say 4'8"

Step 6 - Prepare layout and detailed drawing.

The length L will equal 4'8" and the width 9'4". No riprap will be required for this case.



Elevation - Section



Half Plan - Section

Fig. 1