REMR Technical Note HY-N-1.6

SCOUR PROTECTION DOWNSTREAM FROM GATED LOW-HEAD NAVIGATION DAMS

PURPOSE: To provide guidance on scour protection requirements for gated, low-head navigation dams.

BACKGROUND: Scour downstream from low-head navigation dams is a widespread problem. Since 1984, a work unit titled "Scour Downstream from Stilling Basins" has investigated repair of scoured areas, mainly below low-head navigation dams since the problems are most prevalent and costly there. This Tech Note covers the results of that study as they pertain to gated, low-head navigation dams.

CAUSES OF SCOUR: Investigations revealed that generally, scour downstream from a gated navigation dam stilling basin may result from:

a. Exposure to excessive hydraulic flow conditions involving velocity, pressure, and turbulence.

b. Leaching and/or piping of the underlying natural bed material through the scour protection material (Ref b & c).

c. Undercutting and raveling of the scour protection material as a result of scour at the end of the protection (Ref b & c).

SCOUR PROTECTION REPAIR AND REHABILITATION: Design of the scour protection for a project depends significantly on stilling basin performance. New projects must consider emergency operations as well as equal gate operation in the design of the stilling basin and scour protection. The repair or rehabilitation of existing stilling basins and scour protection depends on the flow conditions for which the protection must remain stable and on the condition and composition of the exit channel downstream from the stilling basin. The following steps are provided to aid in determining scour protection.

a. Determine the flow condition:

   1. Normal or above normal pool.

   2. Gate operation--i.e., one gate fully open, one gate partially open, or all gates operated equally.

   3. Normal or minimum tailwater elevation.

b. Knowing the flow condition, determine the unit discharge through the stilling basin. If single gate criteria are adopted, use the unit discharge through the gate bay in operation for the unit discharge through the stilling basin.

c. Determine the performance of the stilling basin and compute the following theoretical hydraulic parameters illustrated in Figure 1.

v_1 = velocity entering basin

d_1 = entering depth

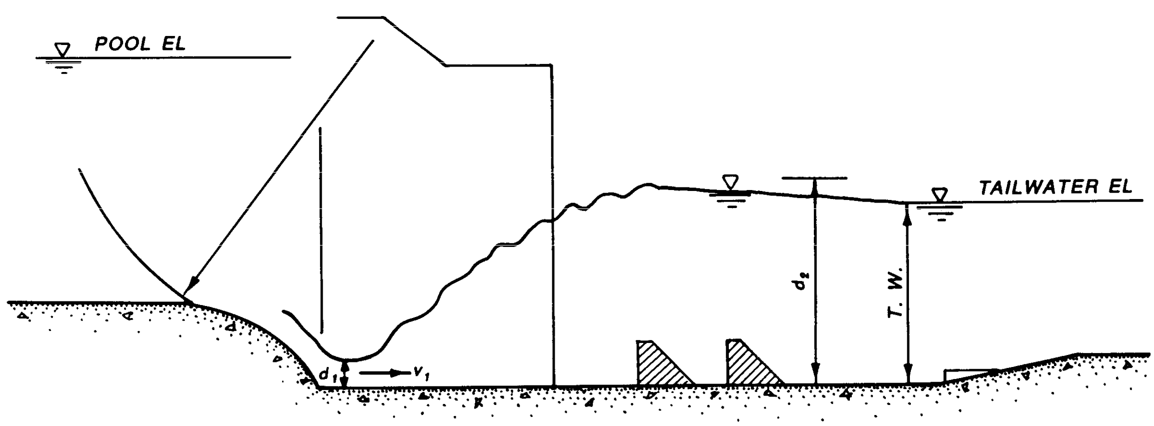
F_1 = entering Froude Number

d_2 = depth after jump

Information on computation of these parameters is given in Ref a and d.

d. Determine the tailwater depth (TW) over the stilling basin floor for the scour protection design condition.

e. Compare the tailwater depth with the value for d_2 computed in step c., and compute the ratio TW/d_2.



ELEVATION

Figure 1. Schematic showing hydraulic parameters

f. Use the following table as a guide in selecting the scour protection:

TW/d_2 at Design Flow	Existing Scour	Scour Protection Needed
<0.85	Severe	Rehabilitate existing stilling basin and repair or replace existing scour protection (suggest model study)
<0.85	Questionable	Determine the extent of scour and repair accordingly. If severe scour, suggest above procedure; if not, see below
<0.85	Minimal	Determine if or how many times the design flow condition for scour protection has occurred. If it has happened yearly, scour protection is probably not needed. If the flow condition has never occurred and the streambed is not scour resistant, some form of scour protection is necessary
>0.85	Severe	Check basin design and possibility of leaching. Check original filter design. If basin is okay, use riprap for scour protection. If basin is not adequate, consider basin rehabilitation and repair or replacement of scour protection. Provide good filter
>0.85	Questionable	Determine extent of scour and provide protection accordingly
>0.85	Minimal	Determine if flow condition for design of scour protection has occurred. If it has happened regularly, no additional scour protection is necessary. If it has not occurred, use a scour protection material

GUIDANCE FOR DIFFERENT LEVELS OF SCOUR PROTECTION:

a. Stilling Basin Rehabilitation. The stilling basin will probably need rehabilitation if sufficient tailwater is not present for the formation of a hydraulic jump in the basin for the design flow condition for scour protection. This condition could be the case for basins with TW/d_2 less than 0.85. A most severe scouring condition occurs when supercritical flow exits the existing stilling basin and the hydraulic jump forms in the downstream channel (Ref a). If the Froude Number is greater than 1.0, supercritical flow is exiting the stilling basin. Severe scour downstream from a stilling basin with this flow condition usually indicates that structural modifications are necessary. These could be installing a secondary stilling basin immediately downstream from the existing one or constructing a tailwater dam to increase the depth of water over the basin. The latter is usually not feasible for a navigation project unless the tailwater dam has a navigation lock.

Secondary stilling basins can be constructed in a number of ways. The most effective and costly is to dewater and construct a newly designed basin. A basin constructed of riprap and tremie concrete may be a viable alternative. Sinking barges below the existing basin has been discussed for some projects. The barges could then be filled with concrete or riprap and tremie concrete. Another method could be driving sheet piling downstream from the existing basin at an appropriate location and back filling from the sheet piling to the existing basin with concrete or riprap and tremie concrete. Since baffle blocks and end sills cannot always be used in basins of this type, an additional length for the secondary basin should be considered, and the apron elevation should be d_2 below the design tailwater elevation. Large, grout-filled fabric bags can possibly be used if they can be anchored to the streambed and reinforced within themselves and to one another. Some form of scour protection is needed downstream from the secondary stilling basins.

b. Scour Protection Consisting of Graded Riprap. Computations may indicate the existing stilling basin is acceptable for the design flow conditions for which the scour protection was designed. Severe scour below such a basin usually means the original scour protection was inadequate. It may have failed because of leaching of the subgrade material, causing the scour protection (usually riprap) to sink and/or to ravel at the termination of the protection, causing the riprap to move downstream, or the original protection may have been too small.

The stability of riprap placed downstream from a stilling basin is affected by the following:

- Stilling basin performance for the design flow condition.
- The shape or slope of the exit channel.
- Underlying filters.
- Specific Weight of riprap.
- Riprap interlocking capability.

A physical model study was used to obtain data for riprap size required downstream from two types of stilling basins and three types of riprap placement. The Type 1 stilling basin was the design from EM 1110-2-1605 and the Type 2 stilling basin was obtained from removing the baffle blocks from the Type 1 stilling basin. The three types of riprap blanket placement are shown in Figure 2.

The following formulas were developed for sizing the required riprap:

For a Type 1 Stilling Basin.

a. Riprap placed as a horizontal blanket (Figure 2a).

$$d_{50} = D'(0.15)\left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)^{\frac{1}{2}} F_{es}\right]^{1.5}$$

b. Riprap placed 1V on 10H upward slope (Figure 2b).

$$d_{50} = D'(0.23)\left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)^{\frac{1}{2}} F_{es}\right]^{1.4}$$

c. Riprap placed 1V on 3H downward slope (Figure 2c).

$$d_{50} = D'(0.16)\left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)^{\frac{1}{2}} F_{es}\right]^{1.3}$$

For a Type 2 Stilling Basin.

a. Riprap placed as a horizontal blanket (Figure 2a).

$$d_{50} = D'(0.40)\left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)^{\frac{1}{2}} F_{es}\right]^{1.5}$$

b. Riprap placed 1V on 10H upward slope (Figure 2b).

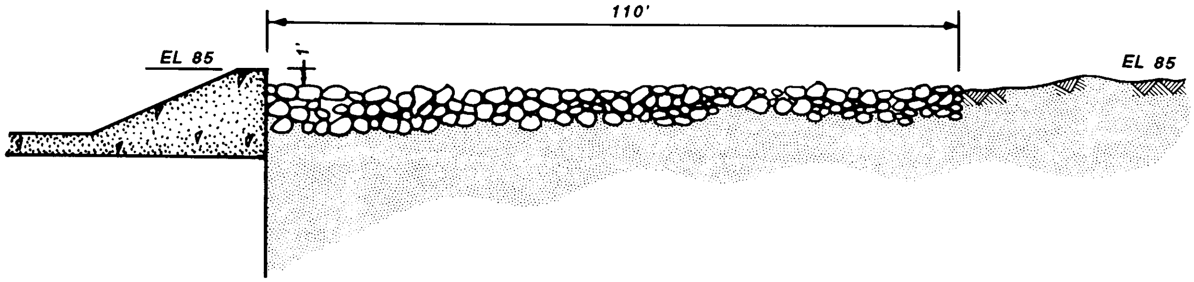
$$d_{50} = D'(0.40)\left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)^{\frac{1}{2}} F_{es}\right]^{1.5}$$

c. Riprap placed 1V on 3H downward slope (Figure 2c).

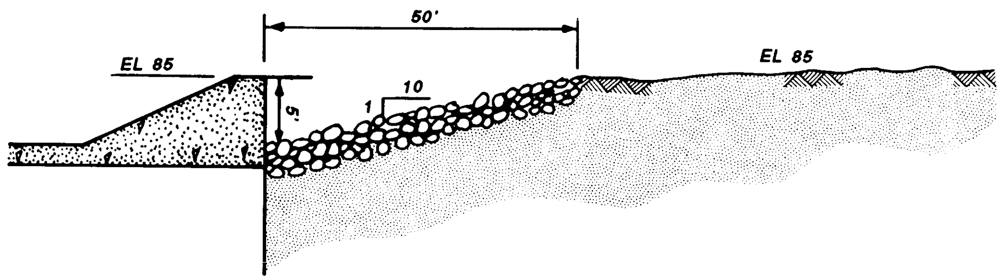
$$d_{50} = D'(0.36)\left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)^{\frac{1}{2}} F_{es}\right]^{1.5}$$

where d_{50} = Riprap diameter at which 50 percent is finer by weight
D' = Depth of flow over end sill
γ_w = Unit weight of water
γ_s = Unit weight of stone
F_{es} = Froude No. at the end sill

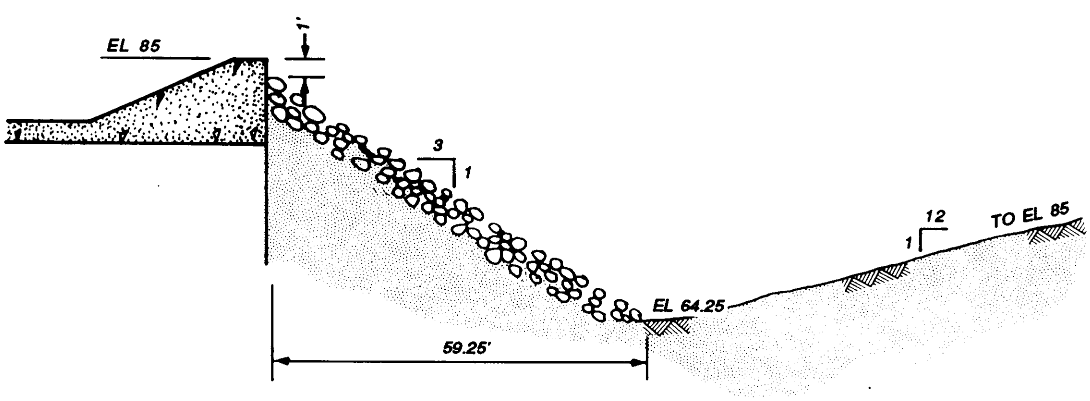
The formulas developed for the Type 1 stilling basin should not be used as guidance in developing riprap scour protection for an existing stilling basin that was not designed according to the guidance in Ref d. The formulas developed for the type 2 basin can be used to determine the minimum d_{50} size stone if the flow conditions and the exit channel configuration are considered



a. Riprap placed as a horizontal blanket.



b. Riprap placed on a 1V on 10H upward sloping blanket.



Riprap placed on a 1V on 3H downward.

Figure 2. Configuration of riprap blanket downstream from stilling basin.

similiar. The most conservative design would be the use of the Ishbash Criteria with C = 0.86 for high turbulence areas (Ref d).

Comparison of laboratory test results for the Type 1 and Type 2 basins and three configurations (Figure 2) of riprap indicate the following:

- Larger riprap is needed for an upward slope downstream from the stilling basin
- A basin without baffle blocks requires considerably larger riprap downstream
- No significant reduction in riprap size was gained from a downward sloping blanket of riprap
- The depth, as well as the average velocity, of flow over the end sill affect the riprap size
- The stilling basin performance significantly affects the riprap size required downstream
- Toe protection at the end of the riprap blanket is needed to prevent raveling at the termination of the protection
- Average velocities greater than 20 ft/sec exiting a stilling basin without baffles will require very large (D_{50} min = 4 ft) riprap.

If riprap with a d_{50} (min) greater than 4 ft is needed, stilling basin rehabilitation, or use of a scour protection material other than riprap should be considered.

c. <u>Alternatives to Riprap.</u> If stilling basin rehabilitation is not feasible and riprap cannot be used to repair an existing scoured area because of the extreme size or cost of transport, alternative scour protection is necessary. Scour protection consisting of materials such as grout-filled fabric bags, concrete cubes, dolos, tetrapods, quadrapods, and tremie concrete have been considered for use at various projects. Dolos, tetrapods, and quadrapods are generally designed as armor units in a coastal environment. Their use in turbulent flow downstream of an energy dissipator would require extensive research to determine design criteria. Generally, the thickness of the underlying layers needed with these units along with the size of the units themselves, preclude their use in the shallow depths typically found downstream from a navigation dam stilling basin. If an inland navigation dam requires scour protection material so large that riprap is not feasible, serious consideration should be given to model tests and stilling basin rehabilitation or replacement.

Previous physical model tests for two site-specific projects have indicated grout-filled fabric bags 20-ft-long by 6.75-ft-wide by 2.75 ft thick can be used instead of riprap that consists of stones 4 to 5 ft in diam. The alignment of the bags was found to affect their stability with certain flow conditions. Previous model tests have also shown that 4-ft concrete cubes provided the same degree of protection as 4- to 5-ft-diam stones. The precast concrete cubes were more stable when placed in an orderly and controlled manner rather than randomly. If large precast units are used as scour protection material in a highly turbulent area, the top layer of filter material underneath the units has to be larger than the voids in the precast units to prevent piping. The orderly and controlled placement of the units minimizes the voids.

d. Caution. Supercritical flow should never be allowed over the scour protection material.

REFERENCES:

a. TR REMR-HY-XXX, "Scour Protection Downstream from Low-Head Navigation Dam Stilling Basins."

b. Department of the Army. 1970. "Hydraulic Design of Floodcontrol Channels," Engineer Manual 1110-2-1601, Washington, DC.

c. Department of the Army. 1986. "Seepage Analysis and Control for Dams," Engineer Manual 1110-2-1901, Washington, DC.

d. Department of the Army. 1987. "Hydraulic Design of Navigation Dams," Engineer Manual 1110-2-1605, Washington, DC.