TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE
Boise, Idaho February 1, 2001

ENGINEERING – NO. 13

DESIGN OF ROCK WEIRS

DESCRIPTION

Porous and solid rock weirs are channel spanning rock structures that are installed to (1) center, and sometimes create, a stream thalweg; (2) protect streambanks by redirecting stream flow; (3) establish and maintain a lower width to depth ratio; (4) provide fish passage by concentrating low flows in flat-bottomed channels into narrower, deeper channels; (5) increase sedimentation along streambanks; (6) control flow direction and therefore minimize meandering; (7) raise water surface elevations to provide water to diversions and channel alcoves; (8) stabilize stream gradient; (9) provide energy dissipation; (10) create pool habitat; and (11) buttress the bole of a rootwad for aquatic habitat cover.

Rock weirs are very low structures that should be completely overtopped during channel-forming flow events (approximately a 1.5-year flow event). Channel-forming flow, or bankfull discharge, is defined as the flow that transports the greatest amount of sediment over a long period of time and controls the channel geometry. Porous weirs have spaces between the exposed rock near the middle of the channel to further accommodate fish passage for some species, while solid weirs are continuous across the channel. Both porous and solid rock weirs are designed in a 'V' or 'U' shape with the trough oriented upstream (see attached figures).

Each stream channel and project site is unique. Geomorphic characteristics, such as meander pattern, width/depth ratio, radius of curvature, particle size distribution, channel gradient, and pool/riffle spacing, all impact the effectiveness of rock weirs. Onsite evaluation of the appropriateness and utility of rock weirs is necessary. They are most effective in gravel- and cobble-bed streams with slopes less than three percent. These structures should NOT be used in sand-bed streams. For streams with a channel-forming flow width greater than 100-feet, 'V' or 'U' shaped weirs are not recommended; 'W' shaped weirs are more effective in very wide streams but are more complex to design and build and are not covered in this technical note.

Rock weirs redirect stream flow to the center of the stream channel and disrupt the velocity gradient in the near-bank region. They utilize a low weir section pointed upstream to force water flowing over the weir into a hydraulic jump. Flowing water turns to an angle perpendicular to the downstream weir face causing the flow to be directed away from the streambank. The weir effect continues to influence the bottom currents even when submerged by flows greater than the channel-forming discharge. The length of the thalweg created downstream varies with slope and radius of curvature, but is typically 100 to 200-

feet. The disruption of the velocity gradient reduces channel bed shear stress and interrupts sediment transport in the near bank region.

Although trees with rootwads can be incorporated into weirs to increase habitat value, they increase the risk of voids in the rock fill, poor foundation conditions and increased uplift forces. If fish habitat is limited, consider creating habitat elements separate from the rock weirs if feasible.

Using rock weirs in conjunction with bioengineering methods is the most favorable combination. The weirs provide direct streambank protection from flow and vegetation provides for energy dissipation and sediment deposition.

GENERAL MATERIAL SPECIFICATIONS

Rock for weirs shall be durable and of suitable quality to assure permanence in the climate in which it is to be used. The rock shall be sound and dense, free from cracks, seams, and other defects that would tend to increase deterioration from weathering, freezing and thawing, or other natural causes. The rock fragments shall be angular to subrounded in shape. The least dimension of an individual rock fragment shall not be less than one-third the greatest dimension of the fragment. Rock will have a minimum specific gravity of 2.5.

Depending on availability, large rock (generally greater than 3-feet in diameter) can be less expensive by weight and can take less time to install. If large rock is not available or is not preferred, follow the rock sizing criteria listed below.

Material sizing should follow standard riprap sizing criteria for turbulent flow (Far West States-Lane Method) for the design flow and be modified with the following formulas (Chapter 16, Engineering Handbook):

$$D_{50\text{-barb}} = 2 \times D_{50\text{-riprap}}$$

$$D_{100\text{-barb}} = 2 \times D_{50\text{-barb}}$$

$$D_{minimum} = 0.75 \times D_{50\text{-riprap}}$$

Note that the Far West States-Lane method gives the riprap D_{75} and not the D_{50} -- a gradation is required to obtain the riprap D_{50}. Once the riprap D_{50} is obtained, use the gradation listed above. When the ratio of curve radius to channel width is less than six, rock sizes become extremely large, and result in a very conservative design.

Rock in the weir should be well graded in the D_{50} to D_{100} range for the weir section (the smaller material may be incorporated into the bank key). The largest rocks should be used in the exposed weir section. DO NOT use the Isbash Curve when sizing rock for rock weirs as it results in sizes too small for this application.

Rock sizing depends on the size of the stream, maximum depth of flow, planform, entrenchment, and ice and debris loading. Adjustments may be necessary for your local area.

GENERAL DESIGN GUIDANCE

see attached figures for reference

(1) **Location** – Rock weirs are typically placed in straight reaches of a stream channel near the downstream end of a riffle section. The upstream tip of the weir should be located at one to two channel widths downstream of the crossover. They should be placed in areas where pools would naturally form. Rock weirs will not protect banks that are eroding due to rapid drawdown or mass slope failure; other techniques should be employed.

(2) **Height** – The height of the weir section near the stream bank (h) is generally determined by the elevation of channel-forming discharge (approximately a 1.5-year event). For ungaged streams, channel-forming discharge can be determined using field indicators such as bed features and the presence or absence of vegetation. The channel-forming elevation is not necessarily the top of the bank; for most streams, the channel-forming elevation is equal to or slightly above average annual peak flow.

To achieve proper weir function the slope is nearly flat (slope should not exceed 1V: 5H) but MUST always have a positive slope towards the center of the channel. Rock weirs that are constructed with flat sections may lose a few rocks in the near bank region resulting in a negative slope essentially forcing water closer to the bank.

Relative height of weirs used in a series is very important. Generally the slope between the weir crests should not be flatter than the pre-project water surface slope at low flows. The center of the weir should be at grade with the channel bed to allow for sediment transport and fish passage. To reduce scour depths, decrease the weir height. Higher weirs cause greater flow convergence, and thus greater scour depths.

(3) **Spacing** – Rock weirs are typically used in a series if the intended purpose is fish passage or grade control with an elevation change (headcut) greater than one-foot. For fish passage, the spacing depends on slope, length of backwater effects created and associated depth, and length of thalweg created downstream. For grade control, the rock weirs should be placed no closer than the net drop divided by the channel slope. As an example, a one-foot high weir in a stream with a two-percent gradient will have a minimum spacing of 50-feet (1/0.02).

(4) **Angle and Offset** – The structure should project upstream such that the flow is directed away from the streambank. The angle from a tangent to the bank can vary from 20 to 60 degrees, although a hydraulic analysis is necessary for weirs with arm angles approaching 60 degrees. Once the arm length reaches 50 to 60-feet, it is necessary to truncate the 'V' and cross the channel in more of a horseshoe shape.

(5) **Profile** – The rock weir transitions from the exposed weir section to the bank key on a slope of 1V:1.5H to 1V:2H. The weir section at the streambank should not exceed the channel-forming flow level (1.5-year flow). The bank key must be long enough and high enough to prevent water from flowing around and eroding behind the structure. Banks that are frequently overtopped will require a more extensive key that extends further back into the bank. Bank material will also need to be considered when designing the dimensions of the key.

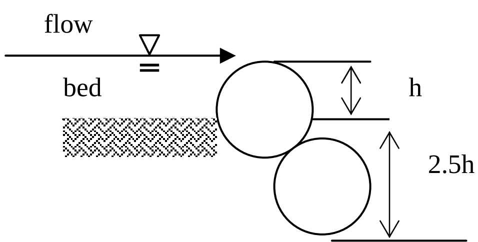
The exposed weir section slopes from the channel-forming flow level at the banks down towards the center of the channel. The center of the weir should be at the desired grade. Alternatively, the center of the weir can be at the grade of the stream channel bottom. The legs of the weir can be maintained at the channel-forming level into the stream channel if the purpose is to reduce channel width and concentrate stream flow. This may be advantageous in streams where fish passage is a concern during low flow periods.

(6) **Width** – The top width of a rock weir generally ranges from one to three-times the $D_{100\text{-weir}}$. The weir width may need to be increased to accommodate construction equipment in large rivers because of the rock weight and track hoe reach. Wider structures will result in a more uniform, stronger hydraulic jump. Wider structures should be used if a deep scour hole downstream of the weir is expected.

(7) **Length of Bank Key** – The purpose of the bank key is to protect the structure from flanking due to near bank erosion. The length of the bank key is 4 times the $D_{100\text{-weir}}$ and should not be less than 1.5 times the height to the top of the bank or eight feet (whichever is greater). Bank key should always be constructed of graded rock. Left over rock, or rock that is too small for the instream portion of the barb can be used in the bank key.

(8) **Depth of the Bed Key** -- The bed key depth should be determined by calculating expected scour hole depth downstream of the weir. The bed key is typically placed to a depth of $D_{100\text{-weir}}$. However, channel excavation depth in a live stream is sometimes limited because of sloughing; a very large rock often works better than trying to place two large rocks on top of one another. Note that scour depth will likely exceed the depth of the thalweg (deepest part of the channel). Scour depths will be greater in streams that are relatively deep or have higher gradients.

In lieu of a scour analysis, scour depth can be estimated using the following:



Expected scour depth for gravel or cobble bed streams can be estimated by:

Scour = 2.5*h

Where h = height of exposed rock relative to bed elevation.

For sand, use 3 to 3.5*h

To reduce scour depths, decrease the weir height. Higher weirs cause greater flow convergence, and thus greater scour depths.

(9) **Hydraulics** – Depth of flow over the weir at channel forming flows can be calculated by:

$D = (Q_{cff} / C\,L)^{2/3}$ where

Q_{cff} is the flow over the weir in cfs

C is a broad crested weir coefficient generally of about 2.8
L is the total length of the weir

The height of flow over the weir added to the height of the weir should not be more than 120% of the average depth of channel forming flow, or excessive backwater effects will be created.

The shallowest depth of water flow over the weir can be approximated by the formula:

$y_2 = (D_{avg} - h)/2$ where

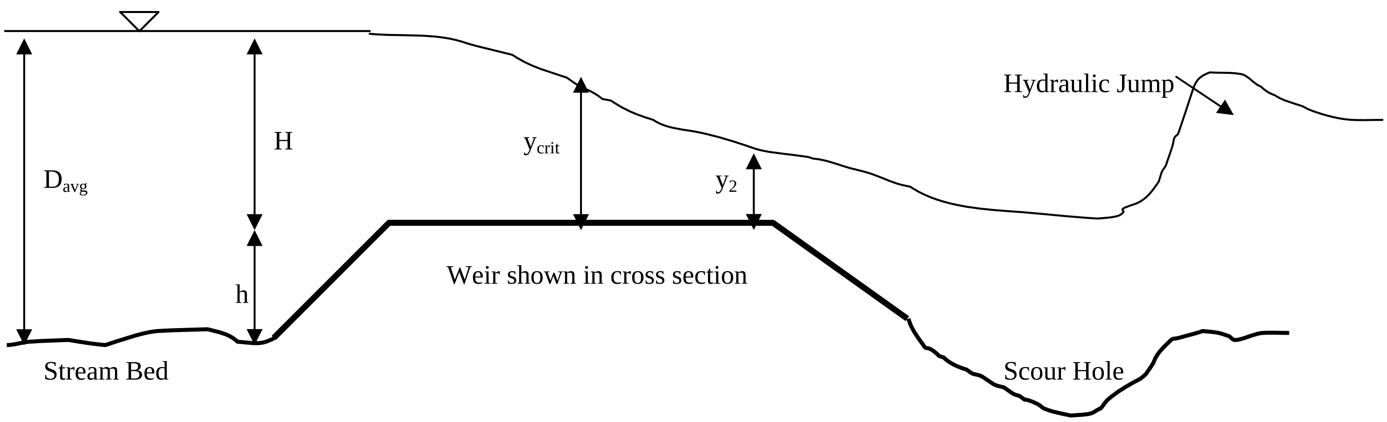
y_2 is the shallowest depth of flow passing over the weir in feet
D_{avg} is the average depth of flow upstream of the weir in feet
h is the height of the weir above the stream bed in feet

The force of the hydraulic jump can then be estimated by calculating the Froude number:

$F = Q_b/((L\ y_2)\ (g\ y_2)^{1/2})$ where

g is the acceleration due to gravity, 32.2 ft/s^2

A Froude number of >1.7 is required. A Froude number of greater than 2.5 is desired. To achieve a higher Froude number, increase the weir height, h, slightly.



(10) **Construction** – Rock weirs should be constructed during low flow conditions to minimize instream disturbances. It is usually necessary to work in the stream channel while constructing rock weirs. The rock should never be dumped. The rock should be placed with the proper equipment to insure that the rocks are interlocked and stable. It is CRITICAL that the designer or an inspector experienced in these structures be present during installation.

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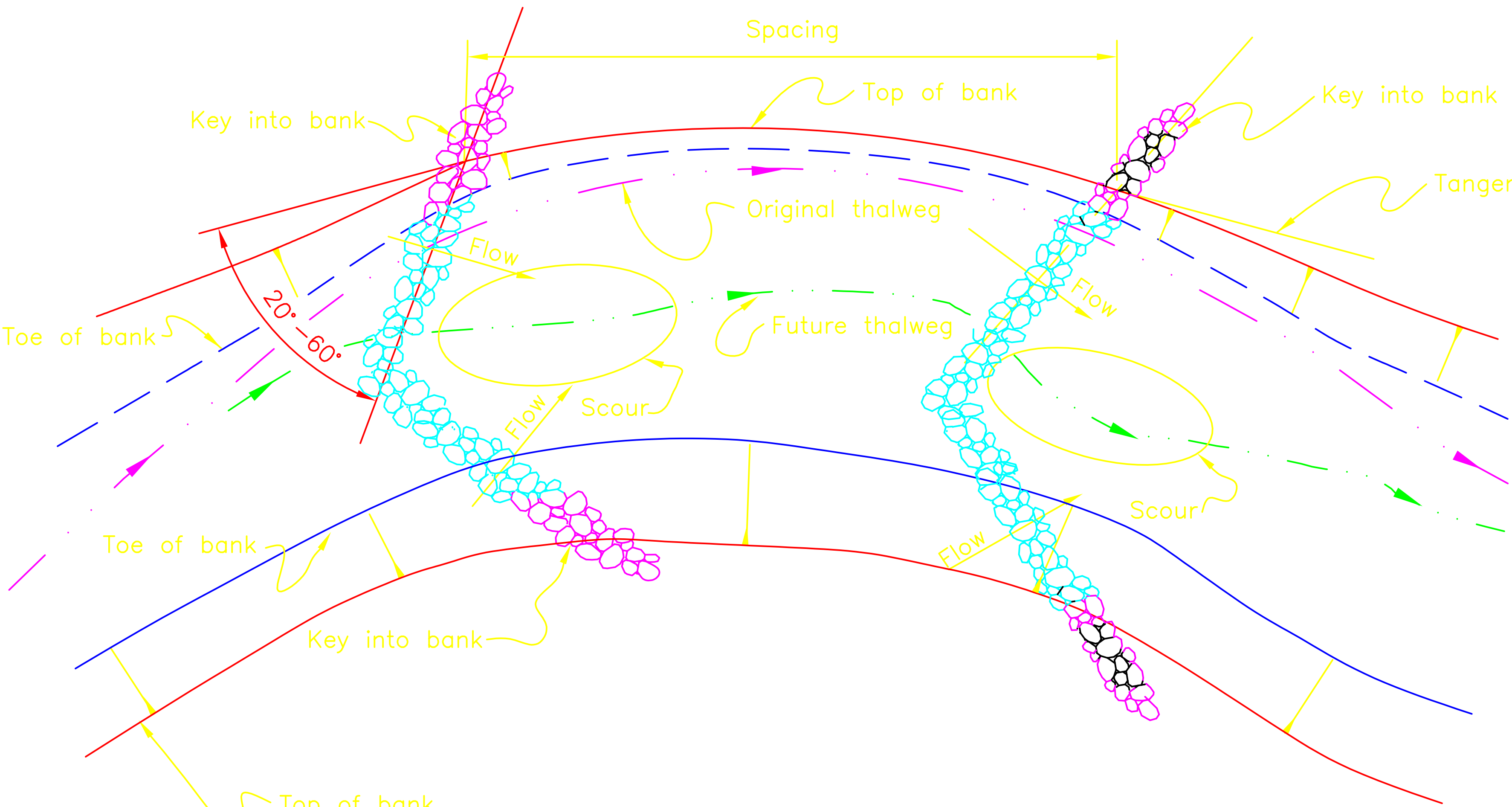
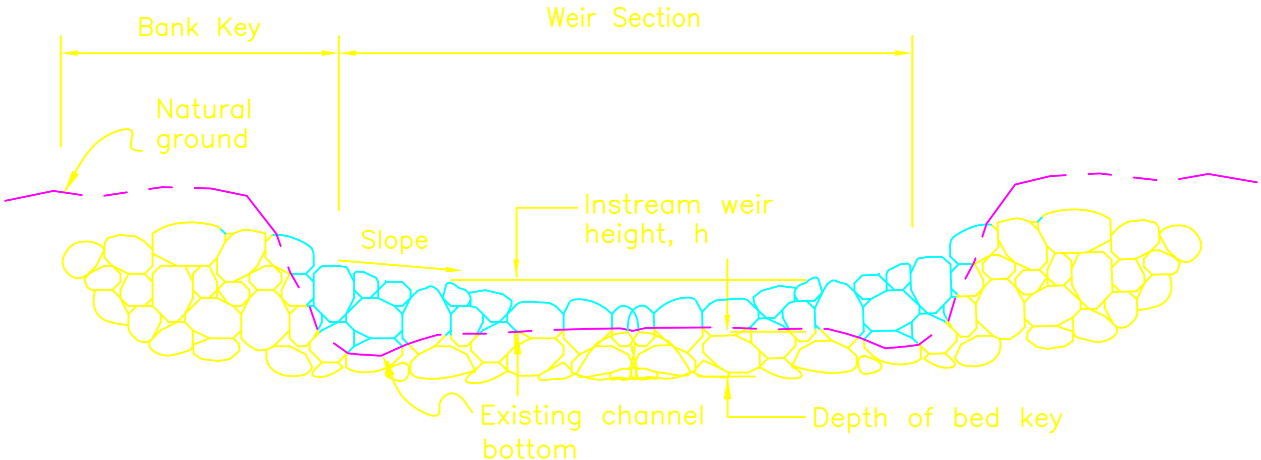
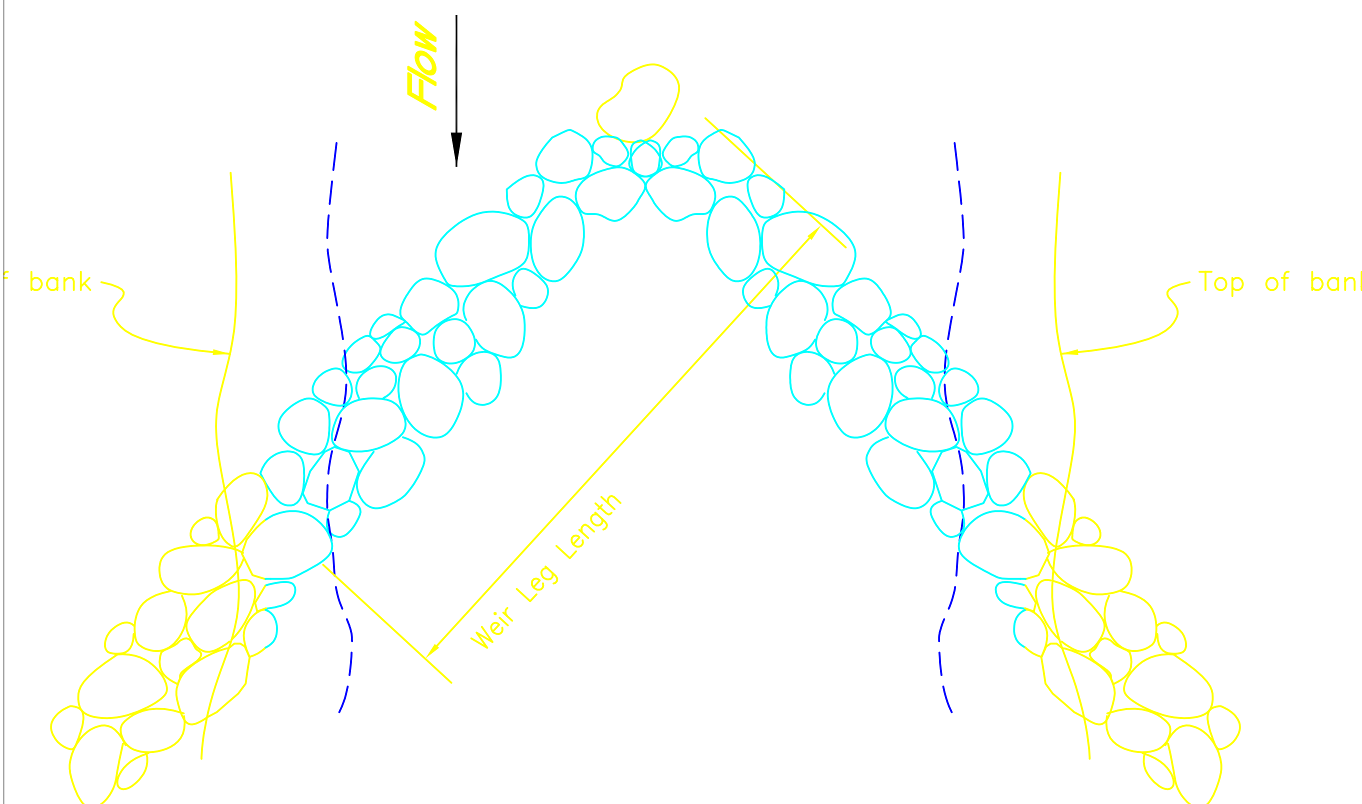


V WEIR

Not to Scale



SIDE VIEW



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V WEIR