Technical Supplement 14M

Vegetated Rock Walls

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Cover photo: Rock walls combine economy of design with physical stabilization and ecological function.

Advisory Note

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

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Vegetated Rock Walls

Purpose

A vegetated rock wall is in the category of mixed-construction bioengineering. Both structural, mechanical, and vegetative elements work together to prevent surface erosion and shallow mass movement by stabilizing and protecting the toe of steep slopes. These types of treatments can provide edge habitat and reduce the need to grade the banks. These walls differ from conventional retaining structures because they are placed against relatively undisturbed earth and are not designed to resist large earth pressures. They are most applicable in high energy streams with narrow riparian corridors.

Introduction

Vegetated rock walls are considered toe walls that are normally 3 to 5 feet high, with 2 to 3 feet below grade for its footing. Rock used to construct the wall should normally range from 8 inches to 3 feet in diameter. Smaller stones may be used to chink or fill the gaps between the larger stone. Usually the stones are dry stacked.

Rectangular shaped rock is often used because it can be stacked better than rounded stone. Larger stones should be used for the base. The foundation for the walls should be firm, undisturbed or well-tamped soil. The wall should be constructed with a 6V:1H external batter angle (fig. TS14M–1).

Figure TS14M–1 Dry stacked stone wall

A sloping bench can be provided behind the wall to serve as a transition slope on which vegetation can be planted. Well tamped backfill should be placed behind the wall and in the spaces between the rocks as they are placed. Live branch cuttings can be placed in the interstices of the rock wall as it is constructed. The butt ends of the branches should extend into the backfill behind the wall. A cross section of a vegetated rock wall is shown in figure TS14M–2.

Construction expertise levels required

The construction of vegetated rock walls is more labor-skill intensive than energy-capital intensive. Well-supervised, skilled labor can be substituted for higher cost, energy-intensive materials and receive excellent results.

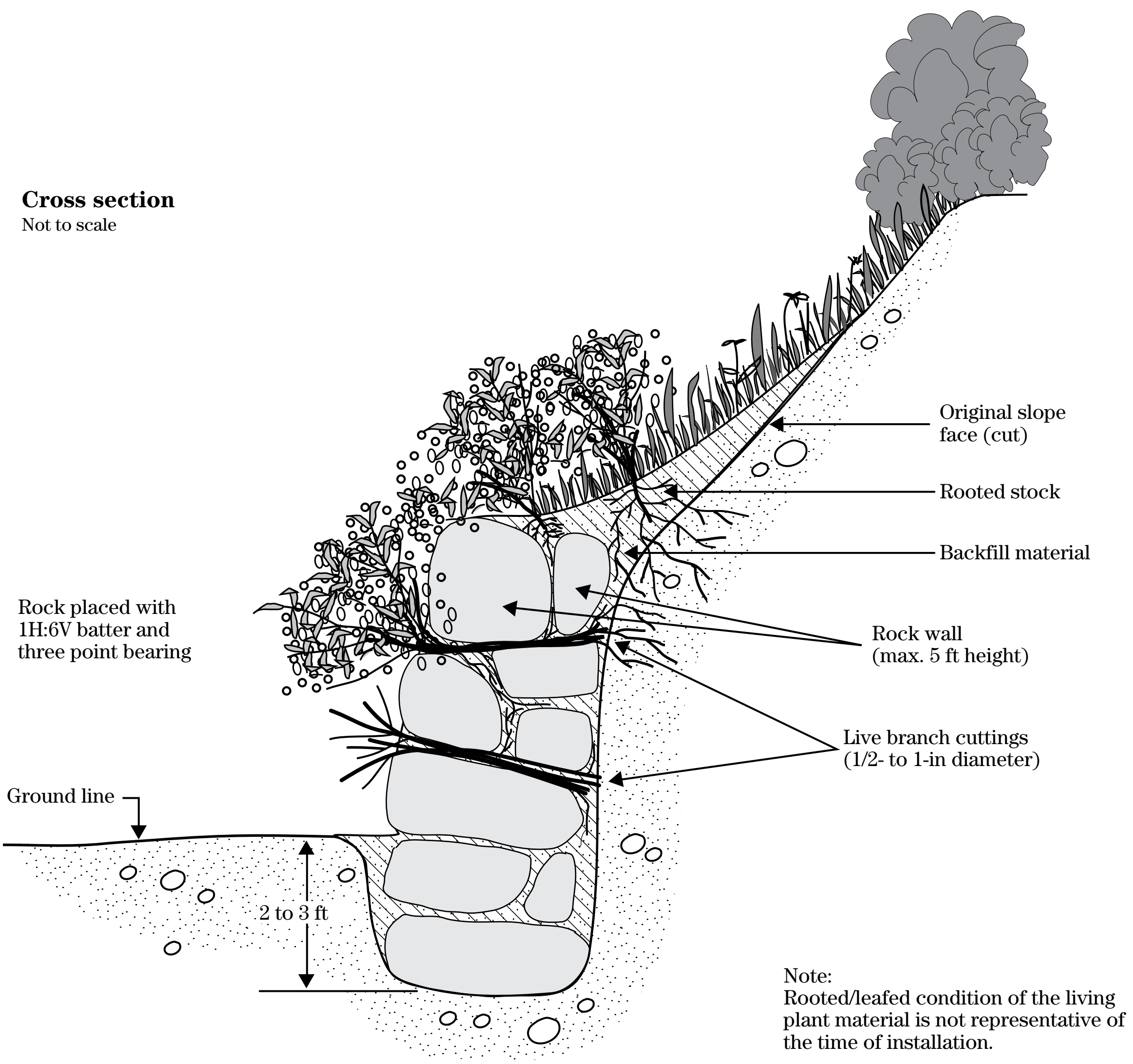
Applications and effectiveness

This system is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness. It is useful where space is limited and natural rock is available.

Analyzing existing slope conditions

Vegetated rock walls are not intended to resist large lateral earth pressures. Their purpose is to stabilize and protect the toe of steep slopes. These walls will not solve the problem of slope instability that is based on the degree of inclination of the slope, the presence of ground water seepage, or the presence of deep-seated, lower strength soils. A complete visual reconnaissance should be made of any slope that is being considered for repair, using toe-wall construction. If a condition other than toe erosion/scour has taken place on a particular slope, such as slope erosion or slope failure, those conditions must be addressed, as well as the toe erosion/scour. In addition to the vegetated rock wall, a combination of scaling, contour-wattling, and brush-layering could be required to stabilize the

Figure TS14M–2 Vegetated rock wall details



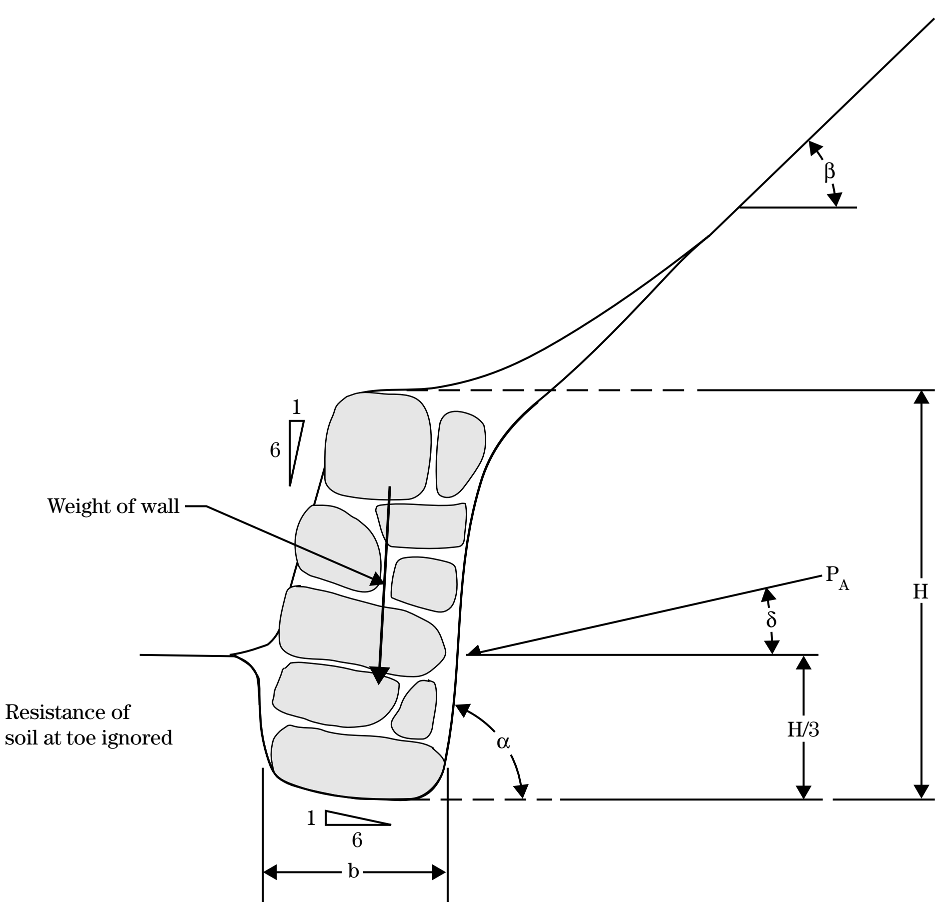
slope (increasing the factor of safety for slope stability). A visual reconnaissance should be followed up by a mechanical analysis of the slope to address its global stability related to slope failure.

Design procedure for establishing width and height

The vegetated rock wall should be analyzed as a massive gravity wall, which requires computations to determine the external, as well as internal, stability of the wall. Internal and external stability calculations of the vegetated rock walls should be performed to determine the stability of the wall against overturning, sliding along the base, sliding along the bedding planes between rock layers, tension stresses at rock layers and the foundation, and bearing capacity failure. These computations include determining the weight of the wall and the lateral force exerted by the soil retained behind the wall. It is generally assumed that hydrostatic pressures will not build up behind the wall. This is a fairly safe assumption, since the walls are generally permeable enough to allow water to drain.

The forces acting on the rock wall are shown in figure TS14M–3. The lateral force acting on the wall can be calculated using Coulomb's equation for lateral earth pressure coefficient, K_A (Coulomb 1776) (eq. TS14M–1):

Figure TS14M–3 Forces acting on vegetated rock wall



$$K_A = \frac{\sin^2(\alpha+\phi)\cos\delta}{\sin\alpha\sin(\alpha-\delta)\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\sin(\alpha-\delta)\sin(\alpha+\beta)}}\right]^2}$$

(eq. TS14M–1)

where:
β = angle of inclination of slope
α = batter angle of wall
ϕ = angle of internal friction of slope soil
δ = angle of wall friction, usually taken as 2/3 of ϕ

Some values for K_A have been tabulated in table TS14M–1. The force is then calculated by equation TS14M–2:

$$P_A = \frac{1}{2}\gamma H^2 K_A \qquad \text{(TS14M–2)}$$

where:
P_A = active earth force per unit length of wall
γ = unit weight of retained soil
H = height of the wall

The resultant of the combined weight of the wall and the lateral earth force must pass through the middle third of the base as shown in figure TS14M–4. The factor of safety against overturning should be greater than or equal to 2.0:

$$\bar{x} = \frac{\sum M_R - \sum M_O}{\text{Wall weight}} \qquad \text{(TS14M–3)}$$

$$\text{with} \quad \frac{b}{3} \le \bar{x} \le \frac{2b}{3}$$

$$\frac{\sum MR}{\sum MO} \ge 2.0 \qquad \text{(TS14M–4)}$$

where:
ΣM_O = overturning moment due to horizontal component of lateral earth force about the toe of the wall
ΣM_R = resisting moment due to the weight of the wall
$\bar{x}$ = distance from toe to point of application of resultant base
b = width of wall

Sliding at the base-to-foundation interface and between the rock layers of the wall should be investigated. It can be assumed that the friction angle between the rock layers is at least equal to the friction angle of the soil. If this is not the case, the sliding stability of the wall must be checked based on the smaller value of the rock-to-rock interface. A factor of safety against sliding should be greater than or equal to 1.5.

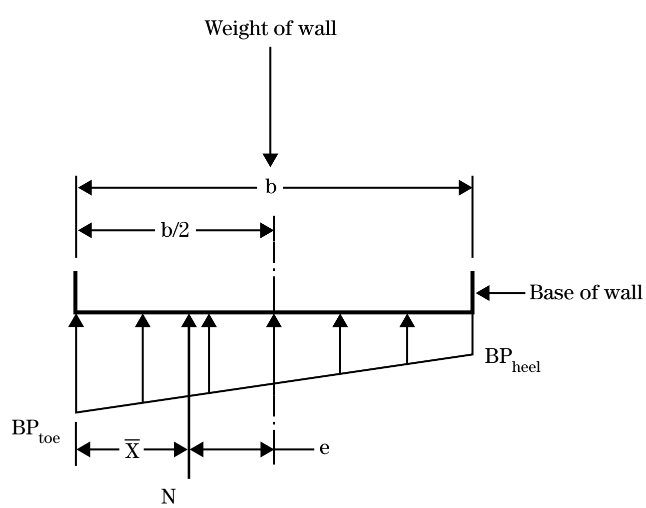
$$\frac{\Sigma F_v \tan\phi}{\Sigma F_H} \ge 1.5 \qquad \text{(TS14M–5)}$$

where:
F_v = weight of the wall (vertical component of lateral earth force ignored)
F_H = summation of horizontal forces against the wall

Table TS14M–1 Coefficient of active earth pressure as a function of internal friction angle and inclination of slope

β =			**0 (deg)**	**10 (deg)**	**20 (deg)**	**30 (deg)**
ϕ = 20	α = 90	δ = 13.33	0.43	0.51	0.88	–
ϕ = 30	α = 90	δ = 20	0.28	0.32	0.39	0.75
ϕ = 40	α = 90	δ = 26.7	0.18	0.20	0.23	0.28

Figure TS14M–4 Bearing pressure distribution at base of wall



Additional resistance to sliding of the wall along its base is provided by embedding the base below the ground line. However, this is ignored due to the fact that the soil in this area could be removed, and this additional resistance would be eliminated.

The bearing pressure at the base of the wall, due to overturning forces and the weight of the wall, should be less than the allowable value for the soil on which the wall bears. Building codes frequently provide allowable bearing pressures for different types of soils, which can be used for the design of vegetated rock walls. The distribution of the bearing stress beneath the wall, which varies from a maximum at the toe to a minimum at the heel of the wall, can be computed using equation TS14M–6:

$$BP = \frac{\sum F_v}{b}\left(1 \pm \frac{6e}{b}\right) \qquad \text{(TS14M–6)}$$

where:
b = width of wall at base

$$e = \frac{b}{2} - \bar{x} \qquad \text{(TS14M–7)}$$

Use the plus (+) sign in equation TS14M–6 to calculate the base pressure at the toe of the wall and the negative (–) sign to calculate the pressure at the heel. The pressure at the toe should be less than the allowable bearing pressure. The pressure at the heel should be less than the allowable bearing pressure, and greater than or equal to zero. A negative pressure at the heel would indicate that the wall is lifting away from the soil at the heel. It could also mean that the wall is lifting at joints between layers of rocks—a potentially dangerous situation. A sudden failure of the wall could happen, since these walls are not reinforced. The width of the wall would need to be increased or the height reduced, if equation TS14M–6 indicates a negative stress or exceeds the allowable bearing pressure. A tension crack that opens will continue to get wider until compressive stresses balance out the tensile stresses.

Finally, it is important that the base of the wall extend below the lowest potential scour elevation. This important issue is not addressed in this technical supplement, but more information on calculating ultimate scour depths is provided in NEH654 TS14B.

Construction guidelines

Figure TS14M–2 shows a typical profile of a vegetated rock wall. Live cuttings should have a diameter of 1/2 to 1 inch and be long enough to reach beyond the rock structure into the fill or undisturbed soil behind the wall. Suggested construction guidelines are:

- Starting at the lowest point of the slope, remove loose soil until a stable base is reached. This usually occurs 2 to 3 feet below ground elevation, but ultimate scour depth should be checked. Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure.
- Excavate the minimum amount from the existing slope to provide a suitable recess for the wall.
- Provide a well-drained base in locations subject to deep frost penetration.
- The vegetated rock wall shall be constructed so that the external wall face has a 6V:1H batter. The rocks should have a slight rearward pitch.
- The rocks should be placed with at least a three-point bearing on the foundation material or underlying rock course. The rock-to-rock contact is maximized.
- The rock should be rectangular or nearly so at the rock-to-rock contact. If not perfectly flat, the thicker end should be placed towards the front of the wall.
- The rock should be placed so that the center of gravity is as low as possible, with the long axis and bedding planes slanting inward toward the slope. As the rocks are placed, fill is laid behind and around the rocks and tamped thoroughly.
- As the wall is built, the layers must be placed in an overlapping pattern, closely adjacent and in a continuous manner to minimize gaps.
- When a rock wall is constructed adjacent to an impervious surface, place a drainage system at the back of the foundation and the outside toe of the wall to provide an appropriate drainage outlet.

- Overall height of the rock wall, including the footing, should not exceed 5 feet.
- A wall can be constructed with a sloping bench behind it to provide a base on which live branch cuttings can be placed during construction.
- Live branch cuttings of shrub-type species of adventitiously rooting material can be placed in the interstices of the rock wall during or after construction. The basal ends of the branches must extend into the backfill or undisturbed soil behind the wall. The live branch cuttings should be oriented perpendicular to the slope contour, with growing tips protruding slightly from the finished rock wall face (fig. TS14M–2).

Conclusion

Vegetated rock walls can provide aesthetic bank protection in confined channels. Their application tends to be in urban and suburban streams. The spaces between the stones can provide edge habitat, and the overhanging vegetation can reduce thermal loading of the streamflow.