Technical Supplement 14E

Use and Design of Soil Anchors

Issued August 2007

Cover photo: Anchoring materials into the streambed and bank can be a significant challenge due to the variable hydraulic forces and the variable earth material strengths.

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.

Technical Supplement 14E

The Use and Design of Soil Anchors

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Purpose

The success of a soil bioengineering project that uses large woody material (LWM) structures depends on proper anchoring design. This technical supplement presents three of the more common anchoring methods used: driven soil anchors, screw-in soil anchors, and cabling to boulders or bedrock. Also covered is a method for estimating the pullout capacity required of the anchor and another method for connecting of the anchor to a LWM structure. Selecting the anchoring method and sizing the anchor require information about the expected streamflows and soil characteristics. The required pullout capacity per anchor can be estimated from the streamflow information, and the anchor type and method can be selected from the soil information. Once the anchor has been installed, the LWM structure must be firmly held into place by the anchor. This requires applying tension to the wire rope that connects the anchor to the LWM structure. An effective method for achieving this is described.

Introduction

Anchoring is required to hold LWM structures and brush revetments against streambanks and streambeds. During high flows, material placed in the streambed or on the streambank will be subject to drag forces, buoyancy forces, and, possibly, impact forces. Proper anchoring is required to resist these forces and firmly hold the structure in place. Since impact forces are difficult to predict, the factor of safety used in the calculations is assumed to be sufficient to account for impact forces.

Failure of an anchoring system on a LWM structure could cause damage to the embankment and downstream structures. Undersized anchors and loose connections contribute to the majority of failures. A proper connection is required between an anchor and a LWM structure to firmly hold the structure in place.

Calculating the forces acting on a LWM structure

Before the anchor method and anchor size can be selected, an estimation of the needed pullout capacity per anchor must be calculated. A simplified method for estimating the forces acting on a LWM structure is provided in this technical supplement. This approach uses project-specific information about soil characteristics, stream velocity at a flow that submerges the structure, and debris load. Much of the information used in this approach will be difficult to obtain or approximate. As a result, a factor of safety is used to account for the lack of data. The designer must consider the impact of an anchor failure when determining the factor of safety.

Soil anchor types

Soil anchors are an effective way to anchor LWM structures. The two types described here are driven anchors and screw anchors. Both anchors are available in different configurations and sizes, with various holding capacities. The anchors can be installed manually in certain soil conditions and have pullout capacities of up to 5,000 pounds. Much greater pullout capacities can be obtained with both anchor types, but a mechanical means of installation is required. Estimates of pullout capacities for anchors in different classes of soils are available in tables published by the manufacturers.

Driven anchors

Driven-type soil anchors are available in different configurations and sizes. They are pushed vertically into the soil to the recommended depth and then are locked into a horizontal position.

Information and supply can be obtained from vineyard, landscape, and utility supply companies. Some of the more common trade names are:

- Duckbill®
- Platipus Stealth®

- Manta Ray®
- Platipus Bat®
- Stingray®

The Duckbill® and the Platipus Stealth® (fig. TS14E–1) are similar in that they are cylindrical-shaped anchors with approximately equal pullout capacities. They are referred to as low-capacity anchors in this technical supplement. The Manta Ray® and Platipus Bat® also can be grouped as similar anchors since they have similar shape and pullout capacities. They are referred to as medium-capacity anchors in this technical supplement. In easy-to-penetrate soils such as wet silts and clays, the Manta Ray® and Platipus Bat® anchors can be installed using a jackhammer, but in most other soils, installation will require heavy equipment.

Stingray® anchors are referred to as high-capacity anchors in this technical supplement. They are more difficult to install, but achieve considerably greater pullout capacities. The Stingray® anchors require heavy equipment for installation.

The pullout capacity of specific driven anchors can be determined from manufacturer tables. Various manufacturer tables are provided at the end of this technical supplement as a guide for anchor selection.

Normally, wherever a stake can be driven or a hole can be drilled, a driven-type anchor can be installed. The anchor is driven by using a drive rod (fig. TS14E–2) to push the anchor to the specified depth into the soil. Note that the bar in figure TS14E–2 has a tapered end, so it is easily removable from the soil anchor. It is important that the soil anchor be driven as close as possible to parallel with the direction of the pull force.

Multiple methods can be used to provide the force needed to push the anchor into the soil. A smaller

Figure TS14E–1 Platipus Stealth® anchor

Figure TS14E–2 Drive rod being inserted into Duckbill® anchor prior to installation

anchor can be driven with a sledgehammer or a post-driver in easy-to-penetrate soils (fig. TS14E–3).

In soils that are harder to penetrate, such as compacted gravels, a jackhammer is effective. Figure TS14E–4 shows a 30-pound jackhammer being used to drive a Duckbill® model 88 anchor into such soils. On this particular job, the manual method of using a sledgehammer was tried without success, but the 30-pound jackhammer was very effective. In soils and soft rock that are very hard to penetrate, a pilot hole can be drilled to assist the installation of a cylindrically shaped soil anchor. Manufacturer specifications should be reviewed for size of pilot holes for the anchor being used.

If greater holding capacities are required, a plate-type anchor, such as a Manta Ray® soil anchor or similar, can be used. In easy-to-penetrate soils, Manta Ray® anchors can be driven with a jackhammer. In medium to hard soils, larger equipment, such as a backhoe with a vibratory plate attachment or a rock breaker attachment, is necessary. Once the soil type and required holding capacity are known, manufacturer data should be used to determine the appropriate size for this type of anchor.

Once a driven-type soil anchor has been pushed to the specified depth, it must be locked into place. This is done by applying tension to the anchor cable. As the anchor cable is pulled up, the bill of the flat part of the anchor catches the edge of the pilot or drive hole. This causes the anchor plate to rotate 90 degrees from its driven position. The anchor now presents its maximum surface area against the pulling forces.

In the locked position, the anchor is capable of obtaining its ultimate holding capacity for the particular soil and depth. In easy-to-penetrate soils, small anchors can be locked using a lever mechanism, such as the

Figure TS14E–3 Post driver being used to install soil anchors

Figure TS14E–4 Driving soil anchor with a 30-lb jackhammer

drive bar, to pry the anchor into the locked position. In soils that are harder to penetrate, a Hi-Lift® jack (fig. TS14E–5) can be used to lock the anchor. Figure TS14E–6 shows a Hi-Lift® jack being used to lock a Duckbill® anchor. Larger anchors require an anchor-locking base with a hydraulic ram system that is made specifically for locking the anchor into position and proof-testing the holding capacity of the anchor. The proof-tested holding capacity should be compared with design values to assure adequate anchorage.

Screw-in anchors

Screw-in soil anchors (fig. TS14E–7) are another option for anchoring LWM. Screw-in anchors can be used in loose to medium dense, fine to coarse sand and sandy gravels, and firm to very stiff silts and clays. They can have a single helical disk or multiple disks that, when rotated, will auger itself into the soil. These anchors are available in multiple sizes. Smaller screw-in soil anchors, like the ones that can be purchased at a farm supply store, can be installed in silty clay soils without rocks by manually screwing them in, using a cross bar. These manually installed anchors can achieve pull-out capacities of up to 4,000 pounds. Larger screw-in soil anchors require heavy equipment for installation. Drilling attachments for tractors, backhoes, and boom trucks are commonly used to install large screw-in soil anchors. The anchor must be installed parallel with the direction of pull.

Figure TS14E–5 Hi-Lift® jack

Figure TS14E–6 Hi-Lift® jack being used to load-lock a Duckbill® anchor

Figure TS14E–7 Screw-in anchor

Cabling (wire rope) to boulders or bedrock

Boulders or bedrock, when available, can be used to anchor structures. Boulders may exist onsite or be incorporated into the design for bank toe stabilizing. Whichever the case, it is possible to strategically place the boulders so that they can be used as anchors. Figure TS14E–8 shows boulders being used for bank toe stabilization, as well as anchors for a brush revetment.

Cabling to boulders or bedrock requires drilling a hole in the rock and using epoxy to secure an eyebolt (fig. TS14E–9) or the ends of wire rope (fig. TS14E–10) into the rock. Follow the epoxy manufacturers specifications for hole diameter, depth, and time required for the epoxy to set. The hole must be free of dust and debris, and the eyebolt or wire rope must be free of any dust, dirt, and lubrication to allow a proper bond.

Wire rope

Wire rope is typically used to attach LWM structures to the anchors. It comes in a range of sizes, constructions, and materials. The characteristics that are generally most essential in soil bioengineering projects are the breaking strength, flexibility, and corrosion-resistance. Wire rope must be flexible enough to make a tight wrap around a LWM structure. In soil bioengineering projects, the wire rope will be exposed to the weather with portions of the wire rope at times submerged in water or buried in the soil. Using galvanized or stainless steel wire rope can provide added corrosion resistance.

Figure TS14E–8 Boulders serve dual purpose: to stabilize the toe and secure brush revetment

Figure TS14E–9 Eyebolt anchored in boulder with epoxy

Figure TS14E–10 Wire rope anchored in boulder with epoxy

Once the total force per anchor (F_t/Anchor) has been calculated, the breaking strength required of the wire rope can be obtained by multiplying the force per anchor by a minimum factor of safety (FS) of 2 to determine the minimum breaking strength required from the wire rope. A factor of safety of 2 is used to account for corrosion and wear over time, as well as impact forces. A minimum of 1/8-inch-diameter wire rope should be used. However, the designer should not necessarily select the thickest cable available because too thick of a cable may not be flexible enough to secure tightly for some applications.

Connectors and tensioning

Proper tensioning of the wire rope to the LWM is essential. Many problems can result from a loose connection between the anchor and LWM such as oscillating forces resulting in the anchor pulling out, increased erosion of the bank or streambed, or the LWM breaking loose from the wire rope.

An effective method for tensioning wire rope around LWM uses ratcheting type cable clamps (fig. TS14E–11) and a special tensioning tool (fig. TS14E–12). Two pieces of wire rope connected to Duckbill® anchors are connected together with a Gripple® wire rope grip One such type is manufactured by Gripple®. The ratcheting type cable clamp is used for connecting two pieces of wire rope or a single piece that is looped back through the wire rope grip. The wire rope grip allows the wire rope to pass through the wire rope grip in one direction only. With the use of the tensioning tool the wire rope is pulled through the wire rope grip, applying tension to the wire rope. Wire rope ratcheting type cable clamps can be obtained in different sizes with working load limits up to 4,000 pounds. Wire clamps can be added if the design indicates that the wire rope grip capacity will be exceeded or as an added precaution after the wire rope has been tensioned.

Figure TS14E–11 Ratcheting-type cable clamp—allows tension to be applied between two cables

Figure TS14E–12 Gripple® wire rope grip and tensioning tool being used to tension down a brush spur

Method for calculating forces acting on a LWM structure

This technical supplement provides a simplified method for calculating forces on a LWM structure. A more detailed approach is provided in technical supplement 14J of this handbook. The resulting calculation can be used to select the appropriate soil anchor. It should be noted that this simplification may not be applicable in all situations, and a more involved analysis may be necessary.

The forces acting on a LWM structure include the drag force from the water flow, a buoyancy force, and impact forces from debris. Since impact forces are less predictable, the equation includes potential impact forces by increasing the debris or increasing the factor of safety.

Drag force

The following empirical equation, based on Stoke's Law (Stokes 1851), can be used to estimate the drag force (F_d) in pounds on the LWM structure:

$$F_d = 0.95(A)(\nu)^2(D)(K) \qquad \text{(eq. TS14E–1)}$$

where:

A = surface area (ft^2) of the LWM structure that is perpendicular to the flow and exposed to the current. This area should include the areas of voids that could potentially fill with debris.

Many LWM structures will have irregular surface areas; for example, full size trees with branches still attached, rootwads, or multiple trees and brush attached together to create one structure. The following methods can be used to account for the irregular, semipermeable areas, each of which requires an estimation of the void areas.

Method 1—First, estimate the surface area of the whole structure including the voids. Then, estimate the percent of the area that is voids that is not anticipated to plug or fill with debris, and subtract it from the surface area of the structure. If this method is used, the permeability coefficient (K) should be 1.0.

Method 2—First, estimate the surface area of the whole structure including the voids, and use that as the surface area (A). Then, use the permeability coefficient (K) to account for the voids in the structure.

ν = expected stream velocity (ft/s)
D = estimated debris increase factor

The debris increase factor is generally between 1 and 1.5. Estimating this factor requires engineering judgment from observation of the debris load on existing stationary objects within the stream and potential for the addition of debris from the streambanks and tributaries. Take notice of the debris load on bridge columns and/or abutments, fallen trees that extend into the stream or have lodged within the stream, or any other stationary object within the stream that could catch debris. Figure TS14E–13 shows an example of a stream with potential for additional debris load on a LWM structure. From these observations and considering the potential damage if an anchor failed, estimate the percent increase in surface area that is perpendicular to the flow, and use that as the debris increase factor.

K = permeability coefficient

This factor is figured by estimating the percentage of voids in the surface area that are not anticipated to plug/fill with debris. Use conservative judgments when making this estimate. If method 1 is used to calculate the surface area, the permeability coefficient (K) is 1.0.

Figure TS14E–13 Debris lodged against rootwads

Buoyancy force

The buoyancy force (F_b) can be estimated by:

$$F_b = V\left(\gamma_w - \gamma_{(LWM)}\right) \qquad \text{(eq. TS14E–2)}$$

where:
V = volume (ft^3) of LWM submerged
γ_W = density of water (62.4 lb/ft^3)
$\gamma_{(LWM)}$ = density of LWM (lb/ft^3) (calculated from the following equation)
$\gamma_{(LWM)} = G_S(\gamma_W)(\omega)$

where:
G_S = specific gravity of wood
ω = (1+moisture content, as a decimal)

The unit density (γ) of the LWM can be calculated from the specific gravity of the wood (G_S) and the expected moisture content (ω). The average moisture content of wood that has been air dried for an extended period is 12 percent. For LWM structures using a moisture content of 12 percent would be a good conservative estimate. The specific gravity for different species of wood in the United States is given in table TS14E–5. The USDA Forest Service compiled these tables at their Forest Service Laboratory. Typical unit densities for wood with 12 percent moisture content range from 25 pounds per cubic foot to 40 pounds per cubic foot.

Once the drag force and the buoyancy force have been calculated, the total force per anchor (F_t/Anchor) is calculated using the following equation:

$$\frac{F_t}{\text{anchor}} = \frac{FS\left(F_d + F_b\right)}{A_n} \qquad \text{(eq. TS14E–3)}$$

where:
FS = factor of safety
A_n = number of anchors

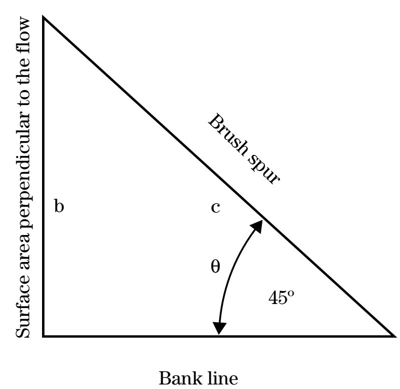
The factor of safety used depends on the potential damages that would occur if an anchor were to fail, as well as the level of confidence in the design assumptions such as potential impact loads from debris and extent of soils information available. Factors of safety for LWM structures typically range from 1.5 (when limited impact loads are expected and soil characteristics are known) to 3.0 (when impact loads are unknown, and/or the soil characteristics are unknown).

Example calculation

Problem:
Brush spurs made from willow brush are designed for a soil bioengineering project to deflect the water flow away from a streambank toe and facilitate the accumulation of sediment between the spurs. The spurs are 20 feet long, 3 feet high, and 3 feet wide and are placed at a 45-degree angle from the streambank, pointing in the upstream direction (fig. TS14E–14). The stream velocity for flow above the brush spur was measured at 4 feet per second. Estimate the force per anchor during a storm event that completely submerges the brush spurs.

Solution:
Estimate the drag force acting on the structure using equation TS14E–1.

Solve for the surface area (A) perpendicular to the flow:



$$A = \text{length} \times \text{height}$$

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} = \frac{b}{c}$$

$$b = 0.707 \times 20\ \text{ft} = 14.1\ \text{ft}$$

$$A = 14.1\ \text{ft} \times 3\ \text{ft (height, given)} = 42.4\ \text{ft}$$

ν = given as 4 ft/s

D = 1.25 (After observation of debris build up on stationary objects within the stream and its tributaries)

$$F_d = 0.95\left(42.4\ \text{ft}^2\right)\left(4\ \text{ft/s}\right)^2\left(1.25\right) \times 1 = 802\ \text{lb}$$

K = 1 (brush spur is well compacted, making it fairly impervious)

Estimate the buoyancy force acting on the structure using equation TS14E–2.

First estimate the density (γ) of the wood using the following equation.

$$\gamma_{(LWM)} = G_S(\gamma_W)(\omega)$$

ω = + 12% = 1.12 (12% is the typical air dried moisture content)
G_S = 0.39 (table TS14E–5)
γ_W = 62.4 lb/ft^3
$\gamma_{(LWM)}$ = 0.39(62.4 lb/ft^3)(1.12)= 27.3 lb/ft^3

Estimate the volume (V) by assuming 60 percent of the brush spur is wood:

$$V = 20\text{ ft}(3\text{ ft})(3\text{ ft})(0.60) = 108\text{ ft}^3$$

So, the buoyancy force (F_b) is:

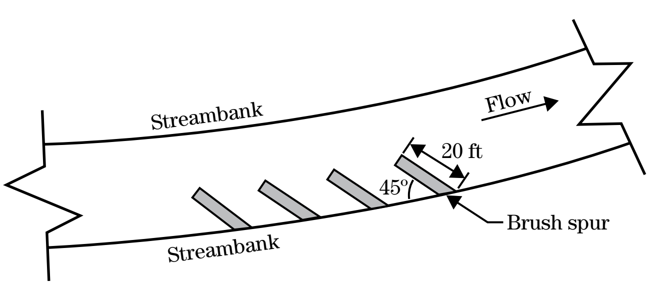
$$F_b = 108(62.4 - 27.3) = 3{,}791\text{ lb}$$

Estimate the total force per anchor (F_t/anchor) using equation TS14E–3.

$$\frac{F_t}{\text{anchor}} = \frac{FS(F_d + F_b)}{A_n}$$

FS = 1.5
A_n = 6 anchors
F_t/anchor = $1.5(802\text{ lb} + 3{,}791\text{ lb}) \div 6 = 1{,}148$ lb/anchor

Figure TS14E–14 Example problem, plan view



Anchor manufacturer data

The anchors in table TS14E–1 (Foresight Products 2001) are rated in an average soil condition (class 5). Soil classes are listed in table TS14E–2 (A.B. Chance Company). A torque probe can be used for quick soil classification in the field. A core sampler could also be used to obtain *in-situ* soil samples, but they are expensive and take time to obtain test results. Higher capacities can be expected in the numerically lower classes and less capacity in the higher number classes. If the soil is something other than a class 5, the rated capacity can be calculated by dividing the actual, if known, or the average probe value for that particular soil by the average probe value for a class 5 soil and multiplying times the rated capacity given in tables TS14E–1, TS14E–3 (Foresight Products 2001), or TS14E–4 (Foresight Products 2001). Generally, resistance to driving an anchor is a good indicator of its pullout capacity, but proof-loading is the only way to ensure the exact pullout capacity of any soil anchor.

Table TS14E–1 Duckbill® specifications (rated for class 5 soils, see table TS14E–2)

Duckbill model no.	Rated capacity (lb)	Drive rod diameter (in)	Normal depth of installation
40	300	1/4	20 in
68	1,100	1/2	2 1/2 ft
88	3,000	3/4	3 1/2 ft
138	5,000	1	5 ft

Table TS14E–2 Soil classification

Class	Description	Probe value
1	Solid bedrock	—
2	Dense clay; compact gravel dense fine sand; laminated rock; slate; schist; sand stone	Over 600 in/lb
3	Shale; broken bedrock; hardpan; compacted gravel clay mixture	500–600 in/lb
4	Gravel; compacted gravel and sand; claypan	400–500 in/lb
5	Medium-firm clay; loose standard gravel; compacted coarse sand	300–400 in/lb
6	Medium-firm clay; loose course sand; clayey silt; compact fine sand	200–300 in/lb
7	Fill; loose fine sand; wet clays; silt	100–200 in/lb
8	Swamp; marsh; saturated silt; humus	Under 100 in/lb

Table TS14E–3 Manta Ray® ultimate holding capacity

Soil description	Blow count (N)	MR–88 ultimate= 10 kips	MR–4 ultimate= 16 kips	MR–3 ultimate= 20 kips	MR–2 ultimate= 40 kips	MR–1 ultimate= 40 kips	MR–SR ultimate= 40 kips	MK–B ultimate= 40 kips
Very dense and/or cemented sands; coarse gravel and cobbles	60+	10 (1,3)	16 (1,3)	20 (1,3)	28–40 (1,3,4)	40 (1,3,)	40 (1,3,5)	40 (1,3,5)
Dense, fine, compacted sands; very hard silts or clays	45–60	6–10 (2,3,4)	9–16 (2,3,4)	17–20 (2,3,4)	21–28 (2,4)	36–40 (1,3,4)	40 (1,3)	40 (1,3,5)
Dense clays, sands and gravels; hard silts and clays	35–50	4–6 (4)	6–9 (4)	12–18 (2,4)	15–22 (2,4)	24–36 (2,4)	32–40 (2,3,4)	40 (1,3)
Medium-dense, sandy gravel, stiff to hard silts and clays	24–40	3–4 (4)	4.5–5.5 (4)	9–14 (4)	12–18 (4)	18–20 (2,4)	24–34 (2,4)	32–40 (2,3,4)
Medium-dense, coarse sand and sandy gravel, stiff to very stiff silts and clays	14–25	2–3 (4)	3.5–4.5 (4)	7–9 (4)	9–12 (4)	15–20 (4)	18–24 (4)	24–32 (2,4)
Loose to medium-dense, fine to coarse sand; firm to stiff clays and silts	7–14	1.5–2.5 (4)	2.5–4 (4)	5–8 (4)	7–10 (4)	10–15 (4)	14–18 (4)	20–24 (4)
Loose fine sand; alluvium; soft clays; fine, saturated, silty sand	4–8	0.9–1.5 (4,6)	1.5–2.5 (4,6)	3–5 (4,6)	5–8 (4,6)	8–12 (4,6)	9–14 (4,6)	13–20 (4,6)

1 = Drilled pilot hole required for efficient installation
2 = Ease of installation may be improved by drilling a pilot hole
3 = Holding capacity limited by ultimate strength of anchors
4 = Holding capacity limited by soil structure
5 = Not recommended in these soils
6 = Wide variation in soil properties reduces prediction accuracy. Preconstruction field test is recommended.

Table TS14E–4 Stingray® ultimate holding capacity

Description	Blow count (N)	SR–1 ultimate = 100 kips	SR–2 ultimate = 100 kips	SR–3 ultimate = 100 kips
Very dense and/or cemented sands; coarse gravel and cobbles	60+	65–89 (1,3)	89–100 (1,3)	100 (1,3,5)
Dense, fine, compacted sand; very hard silts and clays	45–60	58–65 (2, 4)	79–89 (2,4)	100 (2,3)
Dense clays, sands and gravel; hard silts and clays	35–50	39–58 (4)	62–79 (2,4)	85–100 (2,3,4)
Medium dense sandy gravel; very stiff to hard silts and clays	24–40	29–41 (4)	46–66 (4)	63–90 (4)
Medium dense coarse sand and sandy gravel; stiff to very stiff silts and clays	14–25	24–32 (4)	31–48 (4)	48–63 (4)
Loose to medium-dense, fine to coarse sand; firm to stiff clays and silts	7–14	16–24 (4)	27–36 (4)	37–48 (4)
Loose, fine sand; alluvium; soft-firm clays; varied clays; fill	4–8	13–19 (4,6)	19–28 (4,6)	24–37 (4)

1 = Drilled hole required to install
2 = Installation may be difficult; pilot hole may be required
3 = Holding capacity limited by structural rating of anchors
4 = Holding capacity limited by soil structure
5 = Not recommended in these soils
6 = Wide variation in soil properties reduces prediction accuracy. Preconstruction field test recommended

Specific gravity of wood

Tabls TS14E–5 provides a summary of specific gravities for some commercially important wood grown in the United States. The designer may want to adjust these values based on age or condition of the wood used in the project or to provide for a factor of safety.

Conclusion

Proper anchoring of LWM structures is essential to the success of a soil bioengineering project. Choosing the most applicable anchoring method depends on the pullout capacity required of the anchor, site conditions such as streambed and streambank soil characteristics, site access for construction equipment, and material availability.

Site access or equipment availability may be the deciding factor in the anchor method selected. Manual installation may be possible for some projects, but much greater pullout capacities can be achieved from an anchor that requires some type of mechanical installation. For example, driven anchors that require a jackhammer for installation can achieve much greater pullout capacities than ones that can be manually driven. In most locations, a jackhammer and compressor can be rented fairly inexpensively and can greatly decrease the effort and time required to install a driven anchor. Once the anchor has been selected, it is essential that the LWM structure be properly tensioned to the anchor to prevent movement.

Table TS14E–5 Specific gravity values for some commercially important woods grown in the United States

– – – – – – – – – – – – – – – – Hardwood – – – – – – – – – – – – – – – –

Common species	Moisture content	Specific gravity[1]
Alder, red	Green	0.37
	12%	0.41
Ash		
Black	Green	0.45
	12%	0.49
Blue	Green	0.53
	12%	0.58
Green	Green	0.53
	12%	0.56
Oregon	Green	0.5
	12%	0.55
White	Green	0.55
	12%	0.6
Aspen		
Bigtooth	Green	0.36
	12%	0.39
Quaking	Green	0.35
	12%	0.38
Basswood		
American	Green	0.32
	12%	0.37
Beech		
American	Green	0.56
	12%	0.64
Birch		
Paper	Green	0.48
	12%	0.55
Sweet	Green	0.60
	12%	0.65
Yellow	Green	0.55
	12%	0.62
Butternut	Green	0.36
	12%	0.38

Common species	Moisture content	Specific gravity[1]
Cherry		
Black	Green	0.47
	12%	0.50
Chestnut		
American	Green	0.40
	12%	0.43
Cottonwood		
Balsam, Poplar	Green	0.31
	12%	0.34
Black	Green	0.31
	12%	0.35
Eastern	Green	0.37
	12%	0.40
Elm		
American	Green	0.46
	12%	0.50
Rock	Green	0.57
	12%	0.63
Slippery	Green	0.48
	12%	0.53
Hackberry	Green	0.49
	12%	0.53
Hickory, Pecan		
Bitternut	Green	0.60
	12%	0.66
Nutmeg	Green	0.56
	12%	0.60
Pecan	Green	0.60
	12%	0.66
Water	Green	0.61
	12%	0.62

Table TS14E–5 Specific gravity values for some commercially important woods grown in the United States—Continued

Common species	Moisture content	Specific gravity[1]
Hickory, True		
Mockernut	Green	0.64
	12%	0.72
Pignut	Green	0.66
	12%	0.75
Shagbark	Green	0.64
	12%	0.72
Shellbark	Green	0.62
	12%	0.69
Honeylocust	Green	0.60
	12%	—
Locust		
Black	Green	0.66
	12%	0.69
Magnolia		
Cucumbertree	Green	0.44
	12%	0.48
Southern	Green	0.46
	12%	0.50
Maple		
Bigleaf	Green	0.44
	12%	0.48
Black	Green	0.52
	12%	0.57
Red	Green	0.49
	12%	0.54
Silver	Green	0.44
	12%	0.47
Sugar	Green	0.56
	12%	0.63
Oak, Red		
Black	Green	0.56
	12%	0.61
Cherrybark	Green	0.61
	12%	0.68
Laurel	Green	0.56
	12%	0.63
Northern Red	Green	0.56
	12%	0.63
Pin	Green	0.58
	12%	0.63
Scarlet	Green	0.60
	12%	0.67
Southern Red	Green	0.52
	12%	0.59
Water	Green	0.56
	12%	0.63
Willow	Green	0.56
	12%	0.69
Oak, White		
Bur	Green	0.58
	12%	0.64
Chestnut	Green	0.57
	12%	0.66
Live	Green	0.80
	12%	0.88
Overcup	Green	0.57
	12%	0.63
Post	Green	0.60
	12%	0.67
Swamp Chestnut	Green	0.60
	12%	0.67
Swamp White	Green	0.64
	12%	0.72
White	Green	0.60
	12%	0.68
Sweetgum	Green	0.46
	12%	0.52
Sycamore		
American	Green	0.46
	12%	0.49
Tanoak	Green	0.58
	12%	—

Table TS14E–5 Specific gravity values for some commercially important woods grown in the United States—Continued

Common species	Moisture content	Specific gravity[1]
Tupelo		
Black	Green	0.46
	12%	0.50
Water	Green	0.46
	12%	0.50
Walnut		
Black	Green	0.51
	12%	0.55
Willow		
Black	Green	0.36
	12%	0.39

Softwood

Common species	Moisture content	Specific gravity[1]
Baldcypress	Green	0.42
	12%	0.46
Cedar		
Atlantic White	Green	0.31
	12%	0.32
Eastern redceder	Green	0.44
	12%	0.47
Incense	Green	0.35
	12%	0.37
Northern White	Green	0.29
	12%	0.31
Port-Orford	Green	0.39
	12%	0.43
Western redceder	Green	0.31
	12%	0.32
Yellow	Green	0.42
	12%	0.44
Douglas-fir[2]		
Coast	Green	0.45
	12%	0.48
Interior West	Green	0.46
	12%	0.50
Interior North	Green	0.45
	12%	0.48
Interior South	Green	0.43
	12%	0.46
Fir		
Balsam	Green	0.33
	12%	0.35
California Red	Green	0.36
	12%	0.38
Grand	Green	0.35
	12%	0.37
Noble	Green	0.37
	12%	0.39
Pacific Silver	Green	0.40
	12%	0.43
Subalpine	Green	0.31
	12%	0.32
White	Green	0.37
	12%	0.39
Hemlock		
Eastern	Green	0.38
	12%	0.40

Table TS14E–5 Specific gravity values for some commercially important woods grown in the United States—Continued

Common species	Moisture content	Specific gravity[1]
Mountain	Green	0.42
	12%	0.45
Western	Green	0.42
	12%	0.45
Larch		
Western	Green	0.48
	12%	0.52
Pine		
Eastern White	Green	0.34
	12%	0.35
Jack	Green	0.40
	12%	0.43
Loblolly	Green	0.47
	12%	0.51
Lodgepole	Green	0.38
	12%	0.41
Longleaf	Green	0.55
	12%	0.59
Pitch	Green	0.47
	12%	0.52
Pond	Green	0.51
	12%	0.56
Ponderosa	Green	0.38
	12%	0.40
Red	Green	0.41
	12%	0.46
Sand	Green	0.46
	12%	0.48
Shortleaf	Green	0.47
	12%	0.51
Slash	Green	0.54
	12%	0.59
Spruce	Green	0.41
	12%	0.44
Sugar	Green	0.34
	12%	0.36

Common species	Moisture content	Specific gravity[1]
Virginia	Green	0.45
	12%	0.48
Western White	Green	0.35
	12%	0.38
Redwood		
Old-Growth	Green	0.38
	12%	0.40
Young-Growth	Green	0.34
	12%	0.35
Spruce		
Black	Green	0.38
	12%	0.42
Engelmann	Green	0.33
	12%	0.35
Red	Green	0.37
	12%	0.40
Sitka	Green	0.37
	12%	0.40
White	Green	0.33
	12%	0.36
Tamarack	Green	0.49
	12%	0.53