Figures

Photos

None

Chapter 20. Materials

20.1. Native vs. Non-Native Materials

"Native" materials, sometime referred to as "on-site materials," are those materials that occur naturally within the environment or landform through which the trail passes. Native materials enhance the appearance of a trail structure and reduce the visual impact of the trail by blending it into the surroundings. When native materials are used, they should be of a sustainable quality.

Materials for trail construction that are imported to the worksite and not gathered or produced locally are considered "non-native." Use of non-native materials is appropriate when native materials are unavailable, harvesting of native materials is detrimental to the resources, or non-native materials are more cost effective or provide a safer, more durable product. Imported rock, gravel, and soil must be durable and an appropriate color that blends with the area the trail traverses. All material must be free of invasive and exotic weeds, pathogens, and organisms.

20.1.1. Cost Benefit Analysis

To help determine which materials to use, perform a cost benefit analysis between the use of native and non-native materials. Utilizing native resources may reduce material and labor costs, particularly in remote locations where materials have to be transported over a long distance. Consider costs related to the purchase, harvest, and transportation of materials and restoration of the harvest site. Guidelines for trail and site rehabilitation are used for restoration of source areas. (See Chapter 27, *Trail Removal and Site Restoration.*) In addition, evaluate the potential resource impacts of using native materials. Finally evaluate the durability, longevity, aesthetic, and architectural characteristics of the material.

20.1.2. Environmental Analysis and Permits

The use of any on-site materials must be disclosed in the project's environmental documents, reviewed by natural and cultural resource specialists, and approved during the environmental review process. The use of native materials may require mitigation measures and control agency permits. All approvals and permits must be secured before native materials are harvested. Prior to the start of the trail project, all CEQA documents, mitigation measures, and permit conditions must be reviewed with the trail crew, including the location of all approved and permitted native materials and the marking or flagging of those sites.

20.2. Soil

20.2.1. Native

Soil can be used as fill material for a variety of trail structures including retaining walls, approach ramps, turnpikes, causeways, and step treads. It can also be used to cover exposed roots and rocks or help bind and soften the appearance of aggregate surfacing. Soil should be harvested from sources in the following order:

1. From performing maintenance and construction on trail facilities:
   a. Excavated soil from trail or trail structure construction;
   b. Slough and berm material produced from restoring back slopes and/or outsloping the trail bed; and
   c. Cleaning of silt deposits from drainage structures.
2. Silt from point bars in streams or rivers where vegetation is not disturbed.
3. Soil borrow pits.

It should be noted that native soil types can vary widely depending on location. When using native soil, care should be taken to match the appropriate soil type with the purpose for which it is being used. If necessary, it may be better to use non-native materials for longevity and sustainability.

20.2.2. Non-Native

When importing soil to a project, select a soil that has the appropriate color and texture. A thorough review and evaluation must be performed to determine the appropriate soil to be imported. The soil should be sterile and free from pathogens, as well as invasive and exotic plant seeds. If the soil is being used to augment aggregate surfacing, it should have sufficient quantities of clay to bond the aggregate together.

20.3. Aggregate

20.3.1. Native

Similar to soil, aggregate can be used as fill material for a variety of trail structures, including retaining walls, approach ramps, turnpikes, causeways, and step treads as well as hardening a trail's surface. It also can be used to repair holes or depressions in the trail tread or elevate the bottom tier of a rock retaining wall. Aggregate or gravel in any amount should be harvested from sources in the following order:

1. Trail or trail structure construction;
2. Trail reconstruction and trio maintenance activities;
3. Scree slopes (rock smaller than fist size);
4. Beach area of lakes and oceans;
5. Point bars on streams or rivers; and
6. Excavation borrow sites.

20.3.2. Non-Native

Imported aggregate should have a texture and color similar to the soil in the area through which the trail traverses. It should not produce a sharp contrast to the surrounding environment. The aggregate should come from a vendor on the list of surface mines approved and licensed by the State of California. Aggregate imported into an otherwise natural setting cannot be assumed to be free of contaminants.

Imported rock must be evaluated for invasive, noxious seeds and pathogens. A monitoring element should be built into an aggregate surfacing project budget to ensure that any seeds transported into a site will be chemically or mechanically removed.

Imported rock should also be checked for its serpentine content, which could expose trail workers and users to asbestos dust. Additionally, aggregate must have the following qualities:

- Fractured faces are necessary to minimize the space between individual rocks so they fit tightly together. Rocks with these characteristics are produced from open pit or rock quarry sites. The rock is excavated from the earth and ran through a crusher to produce the fractured faces. Rock formations such as shale and chert (a hard, dark, opaque rock composed of silica) provide excellent fractured faces. Rounded aggregate produced from river or stream deposits should be avoided. Even when run through a crusher, this material will have smooth rounded faces that are prone to slippage and will leave gaps between rocks. This material does not lock together and does not produce firm, stable, and durable trail tread.

- Proper gradation is necessary so there is a good matrix of rock sizes. Different sizes ensure there are minimal voids or spaces between rocks. The absence of voids allows the aggregate to bind tightly together, increasing its strength and durability. The matrix must also include a good percentage of rock dust, silt, and clay. Having a mixture of clay in the aggregate is very important because clay bonds to the fractured aggregate and essentially glues it together. Clay retains the moisture that is necessary to keep the aggregate from drying out, losing its structure, and becoming friable.

Generally, the standard Class 2 base rock called for in state highway agency specifications makes poor trail tread material. The standards do not specify crushed rock from open pits or quarries and the material lacks the needed fines and clay to lock the aggregate together. Class 2 base rock is better suited as an underlayment for asphalt. Generally the more “clean dirt” (free of organics and vegetative material) in the aggregate matrix the better it will perform. For this reason it is imperative to visit each quarry source and inspect the aggregate first hand. Bring a bottle of water to moisten the aggregate. Once sufficiently moist, form and compact it into a ball by hand. If it retains its shape and does not fall apart, it’s likely to perform well as tread material. If it won’t form or clump together, it probably lacks sufficient fines and clays. Sometimes the quarry can add soil with good quantities of clay or rock dust into the aggregate. If not, then soil generated from trail tread construction or reconstruction can be mixed into the imported aggregate. Using local soil to augment aggregate requires additional labor that must be factored into the overall project cost.

The following specifications can be used for aggregate surfacing projects. Note, these specifications should serve as a starting point for selecting aggregate and should not replace quarry visits and aggregate inspections. If you are unfamiliar with the aggregate material or have never used it to harden a trail surface, it is a good idea to conduct a test section at least one season in advance of a trail hardening project to see how the material will perform.

For pedestrian, mountain bike, equestrian, and multi-use trails, the rock should be 1.5-inch minus. (See Figure 20.1.) For accessible trails, it should be 0.75-inch minus. (See Figure 20.1.) This rock should be from an open pit or quarry, 100% crushed, and free of vegetable matter and other deleterious substances. It should be readily compactable when watered and rolled to form a firm and stable surface. The crushed rock should be inspected prior to delivery to the worksite to ensure the quality of the material. Crushed rock should conform to the grading requirements shown in the following tables.

1 1/2" Minus Aggregate Grading Requirement Chart

Sieve Sizes	Gradation
2"	100
1 1/2"	87-100
3/4"	45-90
No. 4	20-50
No. 30	6-29
No. 200	0-12

3/4" Minus Aggregate Grading Requirement Chart

Sieve Sizes	"Gradation
1"	100
3/4"	87-100
1/2"	70-85
No. 4	30-65
No. 30	5-35
No. 200	0-12

Figure 20.1 - Aggregate Sizing Chart

20.4. Rock

20.4.1. Native

Rock can be used to construct retaining walls, bridge abutments, steps, causeways, drain lenses, armored drainage crossings, step stone crossings, water bars, culverts, and energy dissipaters. It should be harvested from sources in the following order:

1. Clearing and excavating the trail;
2. Trail reconstruction and trio maintenance;
3. Talus slope rock (fist size or larger), including beaches and ocean shores;
4. Forest floor;
5. Streams or rivers; and
6. Quarry sites.

20.4.2. Non-Native

Imported rock must have the appropriate color, texture, shape, size, structural strength, and durability to construct the intended trail structure. Selecting and importing the appropriate rock is critical. The time and effort to locate and select the proper rock is well spent if the resulting rock structure is sound and blends with the environment. Refer to Chapter 11, *Principles of Trail Construction*, Chapter 13, *Retaining Structures*, Chapter 14, *Drainage Structures*, and Chapter 17, *Trail Steps*, for details on rock structure designs and appropriate sizing. Rock fill that is encapsulated within the structure and not visible from the trail can be of a type and color that does not complement the native environment. Refer to Chapter 13, *Retaining Structures*, for further information on the process and logistics of selecting and sorting rock from a commercial quarry and transporting rock out the trail to the worksite.

20.5. Vegetation for Restoration

20.5.1. Transplanting

Rehabilitation of disturbed areas should include transplanting and seeding of native plant species found in the same watershed. Such vegetation is placed where it would grow naturally. Transplanted vegetation is selected and harvested from areas abundant with the desired species. When completed, the harvested area must be restored to a natural-looking appearance. Do not repeatedly use the same access point when gathering vegetation to limit disturbance to the habitat or altering its appearance. Transplants should blend naturally with the surrounding habitat. Consider the soil type, drainage, and amount of direct sunlight when transplanting. Guidelines for trail rehabilitation are used for harvesting and planting of native vegetation. (See Chapter 27, *Trail Removal and Site Restoration.*)

20.5.2. Types of Vegetation for Transplanting

20.5.2.1. Hardy Plants

Hardy plants for transplanting vary by geographic areas. Consult a qualified resource specialist before developing a vegetation transplanting proposal. Transplanting is most successful when performed during winter months and more successful in forested areas.

20.5.2.2. Natural Humus

Humus taken from downed logs provides a diverse vegetation mix when placed on the ground or on other logs. Natural humus and organic duff layers exist in many environments. Harvest and use of natural organic duff is preferable for introducing native seeds, as it protects from the loss of soil moisture and erosion of disturbed soil due to precipitation.

20.5.2.3. Young Conifers

Use young coniferous trees only if the entire root ball can be obtained and the transplanting takes place during the winter months. Trees should be no larger than four feet tall (five gallon size) for optimum transplant success. Transplanting a nursery log (a downed log in a state of decomposition with small shrubs and trees sprouting from it) is an excellent way to reintroduce conifers to an area.

20.5.3. Seeds

Use seeds of native species that are harvested in the project area or have been purchased and approved as a native seed source for the area.

20.6. Logs

Logs from downed trees can be used to build trail structures such as retaining walls, bridge abutments, turnpikes, bridges, and gadburys. When using native logs, consider the durability and life span of the species of wood selected. Do not over-harvest at sites with decades of harvesting or with a limited amount of suitable logs. As with any work in the forest, signs of disturbance must be restored to a natural state.

20.6.1. Stringers and Retaining Structures

Logs should be harvested from sources in the following order:

1. Trees cut or logged during clearing;
2. Downed trees:
   a. Trees out of sight from the trail corridor where removal would cause no damage to natural or cultural resources;

   b. Trees within sight of the trail, but removing them would cause no damage to the natural or cultural resources and would leave minimal scars that can be easily restored to a natural state; and
3. Standing trees when appropriate for timber stand management or hazardous tree removal.

20.6.2. Split Products

Split products (hand split lumber) can be used for just about any wooden trail structure including bridges, puncheons, timber planking, abutments, retaining walls, steps, railing, fencing, water bars, and sign posts. Certain species of trees, including coastal redwood, giant sequoia, and cedar, provide outstanding split wood products. Harvest logs for split products in a manner that leaves minimal scars that can be easily restored to a natural state. Split wood should be harvested from sources in the following order:
1. Trees cut or logged during clearing; and
2. Downed trees off and out of sight of the trail.

20.6.3. Beach Driftwood Logs

Driftwood logs can be used for retaining walls, turnpikes, steps, and puncheon joists. Logs taken from the shore of an ocean or lake and utilized for trail construction or maintenance projects can add character to a shoreline trail. The following criteria are applied when using beached logs:
1. Logs must be removed and transported to the worksite in a manner that will not damage sensitive beach or dune vegetation or leave visible scars.
2. Logs should be displayed to provide an ocean-washed look with little or no exposed, freshly cut ends.
3. Structures should be engineered and built to sustain tidal or wave action.

20.6.4. Riverbank Downed Logs

Due to the importance of these structures in stream and river systems, they should not be removed for trail projects unless they are at imminent risk of being poached or pose a threat to park resources, property, or facilities.

20.7. Glue Laminated Wood Beams

Glue laminated wood beams (“glulams”) are primarily used for bridge stringers in trail construction**.** Glulam is a stress-rated engineered wooden beam composed of wood laminations known as "lams." Individual pieces of wood are end-jointed (also known as “finger–jointed”) together with a durable, moisture-resistant adhesive to create one long, beam. The grain of the laminations runs parallel with the length of the beam. Glulam beams are versatile and can be used in bridge designs ranging from simple and straight to complex with arches and cambers.

A variety of species of wood can be used to create the individual wood lams in a laminated beam. One of the strongest species is Douglas fir. Because of its superior strength, it is often used in fabricating glulams for use in trail bridges. The pre-engineered laminated beam charts in Chapter 16, *Trail Bridges,* specify using Douglas fir select structural wood.

Beams are manufactured with the strongest laminations at the top and bottom of the beam, where the maximum tension and compression occurs. Some glulam beam manufacturers add to the lamination a Kevlar strip at the bottom of the beam to increase the strength of the beam. The most critical location for potential tension-caused bending of the glulam is the bottom of the glulam beam.

Glulams may be manufactured as “unbalanced” or “balanced.” In unbalanced beams, the quality of the lumber is higher on the tension side of the beam than the quality used on the compression side. Therefore, an unbalanced beam has a different bending stress assigned to the tension and compression zones and must be installed accordingly. To ensure the proper installation of an unbalanced beam, the top of the beam is clearly marked. For unbalanced beams used in trail bridge applications, the compression is on the top of the beam and the tension is on the bottom.

The wood quality in the middle of a balanced beam is symmetrical. Balanced beams are used in applications such as long cantilevers or continuous spans, where either the top or bottom of the beam may receive tension due to live loads. They can also be used in single span applications.

Glulams used in trail bridges are typically installed with the wide face of the laminations perpendicular to the applied load. These are commonly referred to as horizontal laminated members.

One of the most important factors in designing a glulam is camber. Camber is the curvature of the laminated beam. The top center of the beam is higher than the ends of the beam, which compensates for the deflection in the beam caused by dead load (weight of the superstructure), live load (weight of the user), and snow load (weight of the snow, where applicable). Camber for glulam beams is specified as either inches of camber or as a radius of curvature used in the manufacturing process.

In environments with high humidity or significant rainfall, mildew, fungi, and decay are common problems in laminated wood beams. To protect laminated wood beams and prolong their lifespan, the beams in these environments should be treated with a wood preservative or be constructed of rot resistant wood such as Alaskan yellow cedar, Western red cedar, or Port Orford cedar.

If the laminated beams are to be pressure treated with a wood preservative, it is important that beams be ordered to the exact dimensions required and all holes drilled before the wood is pressure treated. Cutting and drilling into beams after treatment will leave exposed wood that will be subject to decay and rot. Topical wood preservatives applied to these exposed surfaces are not as effective as pressure treatment.

20.8. Milled Lumber

20.8.1. Nominal vs. S4S

Milled lumber comes in two sizes: “nominal” (also known as “full dimension” or “rough sawn”) and “S4S” (surfaced on all four sides). Nominal is un-surfaced lumber that is actual size or close to actual size. For example, a nominal 4 x 8-inch board will measure 4 inches wide and 8 inches high. These measurements can vary up to 1/16 inch due to the milling process. A S4S board of 4 x 8 inches will actually measure 3 1/2 x 7 1/4 inches. The reason for the reduced size is that surfacing (running it through a planer) removes approximate 1/4 to 3/8 inch from each side of the board. S4S lumber does not have any variability in sizing as the surfacing process standardizes the dimensions.

It is important to note the differences between these types of lumber because they can affect the layout of trail structures. Throughout this handbook examples are provided on how to layout and construct trail structures. Be aware that these examples will specify whether the lumber is nominal or S4S dimensioned. The layout will vary depending on the dimensions of the lumber.

Nominal lumber is not as common as S4S lumber. The advantages of nominal lumber are that by having larger dimensions, the board has slightly more structural strength and longevity. Since this lumber is rough sawn, it may also have a more rustic appearance. The disadvantage is that it may have some irregularities in its dimensions, requiring minor adjustments in the layout. Also, if the finish of the structure calls for a smooth surface, such as handrails, it will take more labor to draw knife or sand the lumber.

S4S lumber is readily available in most standard lumber sizes. The advantages are that the dimensions are consistent and, if the finish requires a smooth surface, it requires little or no extra labor. The disadvantage is that the smaller size means it has slightly less structural strength and longevity.

Nominal Size	S4S Size	Nominal Size	S4S Size
1 x 3	0.75 x 2.5	4 x 10	3.5 x 9.25
1 x 4	0.75 x 3.5	4 x 12	3.5 x 11.25
1 x 6	0.75 x 5.5	4 x 14	3.5 x 13.25
1 x 8	0.75 x 7.25	4 x 16	3.5 x 15.25
1 x 10	0.75 x 9.25	6 x 6	5.5 x 5.5
1 x 12	0.75 x 11.25	6 x 8	5.5 x 7.5
2 x 3	1.5 x 2.5	6 x 10	5.5 x 9.5
2 x 4	1.5 x 3.5	6 x 12	5.5 x 11.5
2 x 6	1.5 x 5.5	6 x 14	5.5 x 13.5
2 x 8	1.5 x 7.25	6 x 16	5.5 x 15.5
2 x 10	1.5 x 9.25	6 x 18	5.5 x 17.5
2 x 12	1.5 x 11.25	8 x 8	7.5 x 7.5
2 x 14	1.5 x 13.26	8 x 10	7.5 x 9.5
3 x 3	2.5 x 2.5	8 x 12	7.5 x 11.5
3 x 4	2.5 x 3.5	8 x 14	7.5 x 13.5
3 x 6	2.5 x 5.5	8 x 16	7.5 x 15.5
3 x 8	2.5 x 7.25	8 x 18	7.5 x 17.5
3 x 10	2.5 x 9.25	10 x 10	9.5 x 9.5
3 x 12	2.5 x 11.25	10 x 12	9.5 x 11.5
3 x 14	2.5 x 13.25	10 x 14	9.5 x 13.5
3 x 16	2.5 x 15.25	10 x 16	9.5 x 15.5
4 x 4	3.5 x 3.5	10 x 18	9.5 x 17.5
4 x 6	3.5 x 5.5	12 x 12	11.5 x 11.5
4 x 8	3.5 x 7.25	12 x 14	11.5 x 13.5
		12 x 16	11.5 x 15.5

Figure 20.2 - Sizes of Nominal vs. Surfaced Lumber

20.8.2. <u>Natural Wood Products</u>

Determine the origin of all lumber so as to not support the destruction of old growth forests. Use lumber companies that practice sustainable harvesting.

20.8.3. <u>Treated Wood Products</u>

If lumber that is naturally resistant to rot and decay is not available or is cost prohibitive, the use of pressure treated Douglas fir may be appropriate. Its use is dependent on its application and the agency’s policy. This lumber is suitable for retaining structures, abutments, soil dams, bridge stringers, bridging, and post sills. Treated lumber should not be used in areas where the public may come into contact with the wood or where it is in contact with a spring or stream (e.g., a wooden culvert).

20.8.4. Lumber for Posts, Handrails, and Benches

Lumber used for surfaces that come into contact with the public, such as posts, handrails, and benches, should be con heart redwood, cedar, or other non-treated wood that is naturally resistant to rot and decay.

20.8.5. Decking Lumber

Decking material should be con heart redwood, cedar, or pressure treated Douglas fir select structural grade. In addition, decking material should be quarter-sawn (vertical grain).

20.8.6. Bridge Stringers

All milled wood stringers and joists for bridges, puncheons, and boardwalks should be Douglas fir select structural grade. It can be either pressure treated or non-pressure treated lumber, although pressure treated lumber is preferable due to its relative longevity. If another species of wood is used for stringers or joists, the structure must be approved by a structural engineer to meet dead load, live load, seismic, and wind shear specifications.

20.9. Composite and Plastic Lumber

The wood composite and plastics industry changes rapidly and constantly develops new laminates, oriented strand technology, and man-made materials, such as new types of plastic and fiberglass.

20.9.1. Composite Lumber

Composite lumber (made from a mix of wood and plastic materials) has been around for some time now and has received broad use in the trail industry. This material was thought to provide a longer-lasting, more durable product than wooden lumber. However, some composite lumber that has been in service for five to 10 years shows signs of warping, cupping, delamination, and deterioration due to exposure to weather, water, and direct sunlight.

This material is not yet suitable for certain structural applications that require tensile strength (the capacity of a material to withstand longitudinal force), such as longitudinal free spanning structural members like stringers or joists for bridges, puncheons, boardwalks, cribbed abutments, or interlocking retaining walls and handrails. When used as decking, it has less free span capability than wooden products of the same dimensions, and, therefore, requires less spacing between stringers and joists. Also, this material may not be as aesthetically pleasing as natural wood products.

Evaluate the appropriateness of using composite materials as follows:

- Aesthetics (how the material will blend in with the landform or park setting).

- Meeting specific structural design requirements.
- Sustainability and maintenance requirements.

20.9.2. Plastic Lumber

Plastic lumber has been around for several decades. This product has steadily improved over the years and is becoming a viable option for trail builders. Plastic lumber comes in structural and non-structural grades. Non-structural plastic lumber has less structural strength than traditional wooden, metal, or fiberglass materials and has limited use in trail structures. It lacks the tensile strength for free span applications but is very effective when fully supported by the ground and the load is bearing straight down (e.g., mudsills and steps) or used in a vertical position (e.g., non-safety railing applications such as sign posts). It can be used for decking, but like composite lumber, it requires additional joists to shorten the free span length. The structural lumber is reinforced with fiberglass or fiber reinforced polymer rods to give it additional strength. Structural plastic lumber has broader applications and can be used for mudsills, steps, cribbed abutments, interlocking multi-tier retaining walls, post sills, decking, and posts. Another advantage of the structural plastic lumber is that it reduces the number of joists required to support the decking when compared to composite or non-structural plastic lumber.

Plastic lumber comes in a wide variety of colors and dimensions. Below is a chart of sizes and actual dimensions. (See Figure 20.3.) An asterisk (*) identifies those sizes that are available in structural grade.

The lifespan of plastic lumber is still somewhat of an unknown since it has been around for only a short period of time. However, if this material is not exposed to direct sunlight, it should last much longer than conventional wooden decking and, considering its rot-resistant properties, it is expected to last many decades. The anticipated lifespan may more than offset the additional cost of this material. It has less aesthetic appeal than wood or composite lumber but is acceptable in the right setting. In dark colors, such as brown or black, it can also be relatively unobtrusive.

Plastic wood in large dimensions costs three to four times as much as conventional wood. Plastic lumber expands in warm temperatures and contracts in cold temperatures, which means the boards can warp and twist when the ambient temperature varies significantly. In temperatures below freezing, plastic lumber can become brittle and subject to fracturing. Climatic conditions should be a factor when considering the use of plastic lumber. When storing plastic lumber, it should be stacked flat, banded tightly, and stored out of the sun. When used in cool, wet climates, plastic lumber decking can leave a very slippery surface. Some manufacturers offer a textured surface to improve traction. This material is also heavier than wood, which can be a factor when packing it long distances. The color and texture of plastic wood, the need to use power tools, and its heavy weight makes the use of plastic wood more appropriate in frontcountry trail applications.

Lumber Size	Actual Size	Lumber Size	Actual Size
2 1/2" Round	2.25" Diameter	2 x 12 T&G*	1 1/2 x 11 1/4
4" Round	3.9" Diameter	2 x 24	1 15/16 x 24
6" Round	5.9" Diameter	3 x 4*	2 1/2 x 3 1/2
9" Round	8.3" Diameter	3 x 6*	2 1/2 x 5 1/2
10" Round	9.8" Diameter	3 x 8*	2 1/2 x 7 1/2
12" Round	11.8" Diameter	3 x 10*	2 1/2 x 9 3/8
13" Round	12.8" Diameter	3 x 10 T&G*	2 1/2 x 9 1/16
1/2 x 1 1/2	1/2 x 1 1/2	3 x 11*	2 3/4 x 10 1/2
1/2 x 2 1/2	1/2 x 2 1/2	3 x 11 T&G*	2 3/4 x 10 1/2
1/2 x 9 1/2	1/2 x 9 1/2	3 x 12*	2 1/2 x 11 1/4
7/8 x 2 1/8	7/8 x 2 1/8	3 x 12 T&G*	3 x 10 3/8
7/8 x 2 7/8	7/8 x 2 7/8	4 x 4*	3 1/2 x 3 1/2
1 x 3	3/4 x 2 5/8	True 4 x 4*	4 x 4
1 x 4	3/4 x 3 1/2	4 x 5*	3 1/2 x 4 1/2
1 x 6	3/4 x 5 1/2	4 x 6*	3 1/2 x 5 1/2
1 x 6 T&G	3/4 x 6	4 x 8*	3 1/2 x 7 1/2
True 1 x 6 T&G	1 x 6	4 x 10	3 1/2 x 9 1/2
1 x 6 G&G	1 x 5 1/2	4 x 12*	3 1/2 x 11 1/4
1 x 8	3/4 x 7 1/2	4 x 12 T&G*	3 1/2 x 11 1/4
1 x 10	3/4 x 9 1/2	5 x 5*	4 1/2 x 4 1/2
1 1/8 x 1 1/8	1 1/8 x 1 1/8	6 x 6*	5 1/2 x 5 1/2
5/4 x 4*	1 x 3 1/2	6 x 8*	5 1/2 x 7 1/2
5/4 x 6*	1 x 5 1/2	6 x 9*	
5/4 x 6 T&G*	1 x 5 1/2	6 x 10*	5 1/2 x 9 3/8
5/4 x 8*	1 x 7 1/2	6 x 12*	5 1/2 x 11 1/4
5/4 x 10*	1 x 9 1/2	6 x 16	6 x 15 1/2
2 x 2*	1 1/2 x 1 1/2	7 x 7	6 1/2 x 6 1/2
2 x 3*	1 1/2 x 2 1/2	7 x 9*	
2 x 4*	1 1/2 x 3 1/2	8 x 8*	7 1/2 x 7 1/2
2 x 6*	1 1/2 x 5 7/16	8 x 10*	7 1/2 x 9 3/8
2 x 6 Sq Corner	1 1/2 x 5 1/2	8 x 12*	7 1/2 x 11 1/4
True 2 x 7	2 x 7	9 x 9*	9 3/8 x 9 3/8
2 x 8*	1 1/2 x 7 1/2	10 x 10*	9 3/4 x 9 3/4
2 x 10*	1 1/2 x 9 3/8	10 x 12	9.8 x 11.8
2 x 10 T&G*	1 1/2 x 9 3/8	12 x 12*	11 1/4 x 11 1/4
2 x 12*	1 1/2 x 11 1/4	12 x 16	11.8 x 15.7

Figure 20.3 - Plastic Lumber Sizes

20.10. Concrete

Concrete has several applications in the construction and maintenance of trails. Most commonly, it is used for bridge sills and abutments. Concrete provides long-lasting structural support for bridge stringers. It normally outlasts wooden bridge components and can be re-used after the upper portion of the bridge loses its structural integrity and is replaced. Concrete is also suitable for surfacing accessible trails. When properly installed in the right environment, concrete can provide a uniform, durable surface.

The use of concrete in trail construction and maintenance is limited by the accessibility of the worksite and distance from the nearest trailhead. Generally, only small concrete pours can be accomplished in remote locations, due to the problems of transporting materials, mixing the concrete, availability of water, and time for curing.

Concrete is comprised of cement, aggregate, and water. Before pouring concrete, each ingredient must be evaluated for the proper type, size, and volume.

20.10.1. Portland Cement

The type of Portland cement that should be used depends on the application. Type I Portland cement is used in most trail construction. Type II Portland cement, which has slower curing rates, is used for extremely large abutment pours so the concrete does not set up before the pour is finished. Type III Portland cement is used when concrete is being poured in extremely cold weather or the forms need to be pulled (removed) as soon as possible because it requires less curing time.

20.10.2. Aggregate in Concrete

Two classifications of aggregates are utilized in concrete: fine and coarse. Fine aggregate consists of sand graded in size from 1/4-inch maximum diameter to near dust size. Coarse aggregate consists of crushed stone or gravel that is well-graded for size and conformance with specific project plans and specifications. When selecting coarse aggregate, the largest permissible size is used. The larger the aggregate, the less water and cement required to produce quality concrete. The maximum size for coarse aggregate depends on the size and shape of the pour and the distribution of reinforcing steel. The size of coarse aggregate should not exceed 1/5 of the minimum thickness of the pour and 3/4 of the clear spacing between reinforcement bars.

20.10.3. Water in Concrete

Water in concrete converts dry cement and aggregate into a plastic, workable mass, and then chemically reacts to harden the mass into a solid, strong unit. The amount of water used determines the strength of concrete. Too much water thins or dilutes the cement paste and reduces its strength. Water used in concrete must be free of vegetable matter and other organic materials. When using an approved and permitted stream or surface water adjacent to the worksite, special care must be taken to keep it clean. Drinking water is satisfactory for concrete.

20.10.4. Proportions

The proportions of cement, aggregate, and water vary depending on the type of pour, working conditions, and accessibility. Proportions are expressed in terms of sacks of cement per cubic yard of concrete. One sack is 90 pounds of cement.

Abutments and sills require a minimum five-sack mix (five sacks of cement for every cubic yard of concrete). Concrete slabs used for accessible trails require a minimum six-sack mix. The quantities of cement and fine and course aggregate depend on the richness of the mix (the higher the ratio of cement, the richer the mix).

The proportion of cement and fine and coarse aggregate for a five-sack mix are:
- 1 part cement
- 3 parts fine aggregate
- 4 parts coarse aggregate

The proportions of a six-sack mix are:
- 1 part cement
- 2.5 parts fine aggregate
- 3.5 parts coarse aggregate

The quantity of water used depends on the desired consistency and strength. Usually concrete is mixed with the minimum quantity of water sufficient to permit proper handling and placement. As the quantity of water in the concrete mix increases, the consistency of the concrete decreases and correspondingly, the strength of the concrete decreases. The stiffness or consistency of concrete is measured by a "slump test;" filling a cone with wet concrete then inverting the cone so the concrete is no longer supported by the cone. The slump is measured by the reduction in height of the concrete cone after the concrete settles. The slump test is described in Chapter 16, *Trail Bridges*. The desired slump for concrete used in abutments and slabs is a maximum of 3 inches and a minimum of 1 inch.

20.10.5. Calculating Volume

To estimate the quantity of concrete required for a specific project, calculate the volume of the forms to be filled with concrete. When estimating the volume for any concrete project, add 5% to 10% to the total quantity to cover any discrepancies in grading, forming, and spillage. Volume calculations for the most common shapes are shown below.

Rectangular Prism:	Length x Width x Depth = Volume
Example:	20 ft. x 10 ft. x 3 ft. = 600 cu. ft.
	600 cu. ft. ÷ 27 cu. ft./cu. yd.) = 22.22 cu. yd.

Cylinders:	$\text{Radius}^2 \times \pi \times \text{Depth} = \text{Volume}$
Example:	(10 ft. x 10 ft.) x 3.14 x 30 ft. = 9,420 cu. ft.
	9,420 cu. ft. ÷ 27 cu. ft./cu. yd. = 348.89 cu. yd.
Triangular Prism:	1/2 (Base) x Height x Depth = Volume
Example:	1/2 (30 ft.) x 10 ft. x 3 ft. = 450 cu. ft.
	450 cu. ft. ÷ 27 cu. ft./cu. yd. = 16.67 cu. yd.

20.10.6. Preparation

Remove all vegetation, loose earth, mud, and organic material from the sub-grade. The sub-grade must be well compacted (e.g., 95% relative compaction) before receiving concrete. Forms are constructed carefully, securely joined at the corners, and properly braced to prevent bulging or distortion of the desired shape. (See Chapter 16, *Trail Bridges*.) Form boards are sound, clean, and coated with non-staining mineral oil for easy removal. Steel reinforcement bars and wire are free of rust, grease, dirt, or any foreign substance that will reduce the ability to bond with the concrete. Horizontal bars are supported every 4 to 5 feet by wires or metal supports. Rocks or blocks of wood are never used to support reinforcement bars because rocks may not have the proper shape to fully support the reinforcement bar or the rocks' surfaces may be contaminated with a substance that prohibits bonding with the concrete, and wood will eventually rot and leave a void in the concrete. To support the reinforcement bars, concrete dobies should be placed between the reinforcement bars and the ground. Prior to pouring concrete, the sub-grade is thoroughly wetted to prevent it from absorbing water from the concrete. The loss of water from the concrete could seriously impair its structural strength. (See Chapter 16, *Trail Bridges*.)

20.10.7. Placing Concrete

When pouring concrete into forms, always start in a corner and use a square point shovel to spread or move the concrete out from the corner. If a hoe or rake is used, it may segregate the aggregate in the concrete and thus weaken it. Concrete is placed in a maximum lift (depth) of 18 inches. Achieve proper consolidation and avoid honeycombing (voids in the concrete) by spading and/or vibrating the concrete thoroughly. Don't over-vibrate, because it can lead to segregation of aggregates. When using chutes, let the concrete drop freely but no more than 3 to 4 feet. Long, free drops can cause segregation of the aggregates.

When placing concrete on a slope, start at the bottom to provide support for the mix all the way up the slope. Avoid ricocheting concrete against the form boards and reinforcement bars, which can also causes segregation of aggregates and honeycombing.

Once the concrete is placed, strike off the excess material by placing a strike-off board (2 x 4 inches) across the top of the form boards and moving it back and forth in a sawing motion to remove excess concrete and fill in low spots. Immediately after striking off, use a bull float to level ridges and fill voids on a large pour and slab. Floating also helps embed coarse aggregate slightly below the surface.

20.10.8. Finishing

After floating, run an edging trowel between the concrete and the side forms to a depth of 1 inch to create a durable edge. Wait until the concrete has set enough to hold the shape of the edges, then run the edging trowel back and forth between the form boards and concrete. Allow wet spots and sheen to disappear before final troweling. Perform the finish troweling with a steel trowel twice - first to lightly remove surface defects and second for final smoothing. The second troweling is performed only after the concrete has hardened sufficiently and no material adheres to the edge of the trowel.

On concrete trails, contraction joints to control cracking are placed perpendicular to the trail. These joints should be 1/4 inch wide, cut 25% of the way through the concrete's depth (typically 3/4 to 1 inch deep), and should be spaced no more than 24 times the thickness of the slab (e.g. a 4-inch slab should have joints spaced no more than 8 feet apart). Finish trail surfaces by pulling a damp stiff bristled broom over the floated surface to produce a non-skid finish. Concrete trails should not be finished with a steel trowel as it will create a slick walking surface.

20.10.9. Curing

Allow concrete to cure slowly. Cover the surface with water, add a layer of plastic sheeting, or cover the surface with burlap and wet frequently. Temperatures must be kept moderate and water loss must be controlled. Rapid drying can result in cracking and a loss of strength. Concrete should be allowed to cure a minimum of seven days before use. If possible, allow concrete to cure a full month before use. In 28 days, concrete will reach nearly its full strength.

20.10.10. Repairs

Remove all loose and unsound material to provide a secure and durable bond between the old and new concrete. Scarifying, abrading, grinding, and sandblasting will remove loose and deteriorated material and leave a rough bonding surface. If none of these methods are practical, concrete can be cleaned and prepped by using an acid etching solution. After thoroughly wetting the surface with water, brush on muriatic acid. Once applied, the surface is immediately washed and rinsed with water to remove all acid and loose particles. A final brushing with a broom or blowing with compressed air is recommended to create a clean bonding surface.

The type of repair technique employed depends on the extent and type of damage. The three basic repair techniques are full depth, epoxy mortar, and thin latex modified cement overlays.

20.10.10.1. Full Depth Repair

“Full depth repair” is when the damaged concrete is removed to the depth of the original pour. Once properly prepped, the entire area, including the old concrete, is wetted to minimize absorption of water from the new concrete. A thin layer of hydraulic cement is applied to all concrete surfaces and the patch concrete is poured. The patch concrete must have the same properties as the existing concrete, as well as a low slump consistency. It is finished in the same manner as other concrete pours.

20.10.10.2. Epoxy Mortar

Epoxy mortar is ideal for repairing cracks and spalls. It consists of a plastic resin and catalyst in a mixture of aggregate and concrete. Epoxy resin provides excellent bonding between materials with the high strength necessary for thin pours. After wetting all surfaces, apply a thin coat of epoxy bond to the concrete surface. Once it becomes tacky, epoxy mortar is applied to the area to be repaired. The mortar is finished in the same manner as concrete.

20.10.10.3. Thin Latex Overlays

Thin latex modified cement overlays are used to resurface abraded or uneven concrete slabs. By adding latex to Portland cement, the bonding, tensile, compressive, and flexile strengths of the concrete are improved. After being properly prepared and wetted, a latex-cement-sand grout is brushed or broomed onto the concrete surface. The latex modified concrete is placed over the wet grout and screed to the proper elevation. Finishing is performed in the same manner as concrete.

20.10.11. Air Entrainment Additives

Concrete trail structures at high elevation or in a cold climate can be damaged by water expansion inside the concrete. To mitigate this situation, air entrainment additives are mixed into the concrete. These additives create many small air bubbles that are dispersed throughout the concrete. These air bubbles increase the freeze-thaw durability of concrete. Uniform distribution of air bubbles can be achieved through the use of organic additives that stabilize or entrain the air bubbles within the fresh concrete.

20.10.12. Color Additives

Exposed concrete can sometimes appear stark and in contrast to the surrounding environment. A color additive can be used to lessen these visual impacts. Additives come in powder or liquid form in a variety of colors, but earth tones such as browns and grays are usually the most effective. On small concrete pours the color additive is blended into the concrete as it is being mixed on site. On larger concrete pours where the concrete is mixed at the plant, the color additive is added at the plant. To ensure a uniform color, it is important that the color additive be thoroughly blended with the concrete.

20.10.13. Asphalt Concrete

Asphalt concrete, commonly known as asphalt or AC, has several applications in construction and maintenance of trails. The primary use is in surfacing accessible trails, trails with heavy foot traffic, or trails that are constantly exposed to moisture. When selecting asphalt, the size or scope of the job should be taken into account. Any new construction or large asphalt repair patches (one cubic yard or greater) require the use of asphalt concrete hot mix. Small repairs, such as potholes, root damage, or edge fractures, require asphalt concrete cold mix. When purchasing asphalt, the following criteria are used:

- Asphalt concrete must be produced in a central mixing plant and conform to Section 39-3 of the California Department of Transportation's Standard Specifications.
- Aggregates must conform to specifications of half-inch maximum, medium grading, Type B, as specified in Section 39-2.02 of the Standard Specifications.
- Asphalt binder must be AR-2000 to AR-8000 steam-refined asphalt, conforming to Section 92 of the Standard Specifications.
- The amount of binder to be mixed with the aggregate should be between 4% and 7% by weight of the dry aggregate.

20.10.13.1. Estimating Volume

Asphalt is purchased by the ton and when estimating the amount needed for a trail paving project, the volume of asphalt must be converted to tons. On average, a cubic yard of asphalt weighs 4,000 pounds (2 tons). To estimate the number of tons required to pave a trail, first calculate the volume of asphalt needed in cubic feet, convert that volume to cubic yards, and then multiply the number of cubic yards by two (there are two tons in every cubic yard).

$$\frac{\text{(Trail Length x Trail Width x Asphalt Depth)}}{\text{27 cubic feet/cubic yard}} = \text{Cubic Yards of Asphalt}$$

Cubic Yards of Asphalt x 2 Tons/Cubic Yard = Tons of Asphalt

Example:

3,000 ft. x 5 ft. x 0.25 ft. = 3,750 cu. ft.
3,750 ÷ 27 = 139 cu. yds.
139 cu. yds. x 2 tons/cu. yd. = 278 tons

20.10.13.2. Soil Sterilants

In some locations vegetation, especially *equisetum* (horsetail), can grow through asphalt creating eruptions or deformities in the trail's surface. These deformities can accelerate the deterioration of the asphalt and take the trail out of compliance with accessibility standards. To resolve this issue, the soil and aggregate base under the asphalt can be treated with a soil sterilant prior to installing the asphalt. A geotextile fabric treated with a soil sterilant can also be placed beneath the asphalt to prevent vegetation from growing through the asphalt. Where these treatments are prohibited, an alternative trail hardening method such as concrete or aggregate surfacing may be appropriate.

20.10.13.3. Tack Coat

Immediately before applying the tack coat, clean the surface of all dirt and loose material. Apply the tack coat at a rate of 0.02 to 0.10 gallons per square yard and at a temperature between 75 and 130 degrees Fahrenheit. Do not apply tack coat when it is wet or rain is imminent; the atmospheric temperature is below 50 degrees Fahrenheit; or the pavement or base material is below 50 degrees Fahrenheit.

20.10.13.4. Paving

Paving begins at the furthest point on the trail to eliminate the need to haul materials over freshly placed asphalt. Apply asphalt deep enough to produce the planned thickness after compaction (generally 1/4 inch of compaction per inch of asphalt). Spread the asphalt so that no separating of coarse and fine aggregate occurs. Lumps of hardened asphalt should be raked out and discarded. When conforming to existing surfaces, the asphalt is feathered to achieve the correct transition between surfaces. When the asphalt is put down in two or more applications, the joints receive a tack coat and are lapped and not butted together. The finished surface must provide adequate drainage and sheeting of water.

20.10.13.5. Compacting Asphalt

Initial rolling is completed before the asphalt's temperature is below 200 degrees Fahrenheit. Rolling is performed so that cracking, shoving, or displacement does not occur. A minimum of three complete rollings are performed after the initial rolling. The final rolling is completed before the asphalt temperature is less than 150 degrees Fahrenheit. The completed surface must be thoroughly compacted, smooth, and free from ruts, humps, depressions, or irregularities.

20.11. Metal

Metal components are used in many trail structures from bridge stringers to anchor plates to structural components. The choice to use metal components is related to aesthetics and specification requirements of the structure. The natural environment, level of maintenance, structural capability, and aesthetics will dictate requirements for corrosion protection. In desert climates, black steel is appropriate, while in coastal environments corrosion inhibitors are required. Hot dipped galvanized, zinc-plated, stainless steel, aluminum, and painted metal are all corrosion inhibitors. Note, all-weather steel may not be appropriate within two miles of coastal environments.

20.11.1. <u>All Weather Steel</u>

All weather steel is primarily used in the construction of steel I beam bridges, overhead steel truss bridges, and soldier pile with timber lagging retaining walls. All weather steel is the term used to describe structural steel with improved atmospheric corrosion resistance. This steel is high-strength, low-alloy that under normal atmospheric conditions has an enhanced resistance to rusting compared to that of ordinary carbon manganese steel.

In the presence of air and moisture, all low alloy steels have a tendency to rust; the rate of which depends on the amount of exposure to oxygen, moisture, and atmospheric contaminants. As the rusting process progresses, the rust layer forms a barrier to the ingress of oxygen, moisture, and contaminants, and the rate of rusting slows. The rust layers formed on most ordinary structural steel are porous and detach from the metal surface over time and the corrosion cycle commences again. The rate of rusting depends on the harshness of the environment.

With all weather steel, the rusting process starts in the same way, but the specific alloys in the steel produce a stable rust layer that adheres to the base metal and is much less porous than rust that forms on carbon steel. This rust patina develops under alternating wet and dry conditions to produce a protective barrier that impedes further access of oxygen, moisture, and pollutants. The result is a much lower corrosion rate than would be found on ordinary structural steel. Periodic inspection and cleaning should be the only maintenance required to ensure the steel continues to perform satisfactorily. The use of all weather steel is ideal in trail structures where access and/or resources for maintenance are limited.

Although all weather steel is slightly more expensive than ordinary structural steel, savings from the elimination of cyclical painting offsets the higher material cost. Therefore, the cost of an all weather steel bridge is very similar to that of a conventional painted steel alternative.

All weather steel is suitable for use in most locations. However, there are certain environments that can lead to durability problems. All weather steel will not perform in extreme environments and should not be used. Exposure to high concentrations of chloride ions, originating from seawater spray, marine fog, or coastal airborne salt, is detrimental. The hygroscopic nature of salt adversely affects the patina by maintaining moisture on the metal's surface. In general, all weather steel should not be used for bridges within 2 kilometers (1.32 miles) of coastal waters.

Alternating wet and dry cycles are required for the patina to form on all weather steel. In an environment that is continuously wet or damp, such as submersion in water, buried in soil, or covered by vegetation, a corrosion rate similar to that of ordinary structural steel must be expected. If all weather steel is used in such cases, it should be painted and the paint should extend above the level of the water, soil, or vegetation. Damp conditions may also be experienced under a bridge if it is low over the water. For this reason, it is recommended that bridge stringers have a minimum freeboard of 8 feet over water.

Mature all weather steel generally blends in well with the surrounding environment. It is important to note that the color and texture will vary with exposure over time. Initially, all weather steel appears orange-brown, which many be considered unattractive, but the color darkens as the patina begins to form. Usually the steel attains its characteristic uniform dark brown color within two to five years.

The speed with which the patina and the associated color form depends mainly on the environment. In an industrial (sulphur contaminated) atmosphere, the weathering process will generally be more rapid and the final color darker than in a cleaner, rural environment. The texture of all weather steel is influenced by the amount exposure it receives. Surfaces that are vertical, facing south and west, or subjected to frequent wet and dry cycles develop a smooth, fine-grained texture, whereas surfaces that are horizontal, sheltered, or facing north tend to have a coarse, granular texture.

20.11.2. Galvanized Steel

There are many potential uses of galvanized steel in trail construction but the most common applications are fasteners, post brackets, bridges stringers, diaphragms, sway braces, and beam seat brackets. Overhead truss steel bridges can also be galvanized. Galvanized steel is used when the structure will be exposed to corrosive natural elements, such as salt air in coastal areas; however, it also can be submerged in fresh or salt water, buried in soil, or embedded in concrete.

When selecting a galvanized steel product, it is important to use only steel that has been batch hot-dip galvanized. Batch hot-dip galvanizing produces a zinc coating by completely immersing the steel product in a bath (kettle) of molten zinc.

In coastal environments, steel beams that have been batch hot-dip galvanized are a viable alternative for bridge stringers. In temperate coastal environments, the time for first maintenance of batch hot-dip galvanized steel I beam is approximately 70 years (based on 1/4-inch or thicker steel receiving a surface coating 3.9 mils of zinc per the American Society for Testing Materials (ASTM) galvanization standards). Time to first maintenance is not equal to the service life of hot-dip galvanized steel, but instead indicates when 5% of the steel's surface will be rusted. At that point, there will still be a galvanized coating on a majority of the steel, but it will need to be repaired. The steel can be repaired by painting the rusted area or re-galvanizing the surface entirely. If maintenance is performed when needed, the service life of the steel will be dramatically increased.

Bridge stringer size can limit the application of hot-dip galvanizing. The average length of a zinc bath in North America is 40 feet and 55-60 foot kettles are common. However, in most trail bridge projects it is easier to transport bridge stringers to the project site if they are in segments of 20 feet or less. Once on site, the segments can be bolted together. All galvanization companies in California can accommodate a 25 foot long 4- x 6-foot steel I beam.

When bolting hot-dip galvanized I beams together, bolting the I beams to the beam seat brackets, or attaching diaphragms and sway braces, it is good practice to use hot dip galvanized bolts, nuts, and washers. Using fasteners made of dissimilar metals, such as carbon steel, all-weather steel, or some types of stainless steel, can cause corrosion. When using stainless steel fasteners with galvanized metal, use austenitic stainless steel (300 series). Where zinc comes into contact with other metals, the potential for corrosion through a bi-metallic couple exists. Zinc, which comprises the hot-dip galvanized coating, is very high on the galvanic series, which means it will be anodic to most other metals. So, when hot-dip galvanized steel is connected to other metals, the zinc coating will lose metal ions to the underlying base steel. This process causes rapid consumption of the zinc coating and decreases the overall life of the structure.

Once the steel I beam bridge stringers are fabricated, they are shipped to a galvanization vendor. When the galvanization process is complete, the I beams can be shipped to the project site. Shipping costs will vary depending on the length and weight of the I beams and the shipping distance.

20.11.3. <u>Aluminum Alloys</u>

Aluminum alloys are primarily used in the construction of bridges, soldier piles with timber lagging retaining walls, culverts, and open grate decking. Aluminum alloy is a chemical composition where other elements are added to pure aluminum to enhance its properties - primarily to increase its strength. The other elements include iron, silicon, copper, magnesium, manganese, and zinc at levels that combined may make up as much as 15% of the alloy by weight.

There are two principle alloy classifications: wrought and cast. A “wrought” alloy has been worked and pounded into shape. It may have been heated and then cooled slowly to anneal it and make it stronger. Between working it and annealing it, the molecules are brought closer together giving it more strength. A “cast” alloy is when the molten alloy is poured into a mold to give it shape, but it has very little strength and is more brittle than wrought alloy. Because of wrought alloy’s superior tensile strength, it is used in structural applications.

Wrought alloy’s primary appeal is its exceptional strength-to-weight ratio. Aluminum is 66% lighter than steel. It is also far less susceptible to brittle fractures. Whereas steel becomes brittle at low temperatures, aluminum increases in tensile strength at low temperatures. Aluminum naturally produces a protective oxide that coats the exterior and regenerates when scratched. This oxide layer is highly corrosion-resistant, which minimizes maintenance costs and makes it a good option in marine environments.

The wrought alloy commonly used in trail bridge construction is 6061-T6. This alloy is versatile, can be strengthened with a heat treatment, is highly formable and weldable, and has moderately high strength coupled with excellent corrosion resistance. This alloy is specified on the engineered and stamped aluminum truss bridge plans in Appendix I. Fasteners used with aluminum structures should be ASTM F593 Type 316 stainless steel to prevent galvanic corrosion.

Aluminum can be finished in a variety of textures and anodized or painted with any color. Colored aluminum requires cyclical maintenance and painting. It can be polished to provide a glossy sheen, which can be obtrusive in a natural setting. Alternatively, aluminum can be unfinished ("mill finish"), which is the finish a material has as it exits the mill where it was processed. A mill finish will often be dull, grainy, without a luster, and will darken over time, making it is less obtrusive in a natural setting.

Aluminum does not burn and is therefore classified as a "non-combustible construction material." Aluminum alloys will nevertheless melt at around 650°C, which most wildfires exceed. Thus, in fire-prone areas, the use of aluminum alloys may not be appropriate.

Although aluminum alloys have a good weight-to-strength ratio, compared to steel their tensile strength is such that the use of I beam bridge stringers is limited. Long bridge spans require additional structural support in the form of a truss assembly.

20.11.4. Hardware

Bolts, lag screws, nuts, washers, and nails in non-coastal environments should be hot-dipped galvanized to prevent rust and corrosion and increase longevity. Often, electroplated and mechanically zinc-plated fasteners are sold as "galvanized," leading to the assumption that they are hot-dip galvanized. It is important to use products that have been hot-dip galvanized because they have a life expectancy of 35-55 years, while electroplated and mechanically plated nails have a life expectancy of 10-15 years. Hot-dip galvanized bolts have a life expectancy of 50+ years while electroplated and mechanically plated bolts have a life expectancy of 15+ years. In coastal environments, stainless steel hardware should be used because it is the most resistant to salt air corrosion. Rods should be cold-rolled steel. Plate or sheet steel should be hot-dipped galvanized or all-weather steel. Repairs to galvanized steel components should be coated with a zinc-rich paint.

Nails are commonly used in assembling and fastening trail structures. Nails should be hot-dipped galvanized to reduce corrosion and increase longevity. The chart below is provided as reference for identifying and selecting appropriate nail lengths.

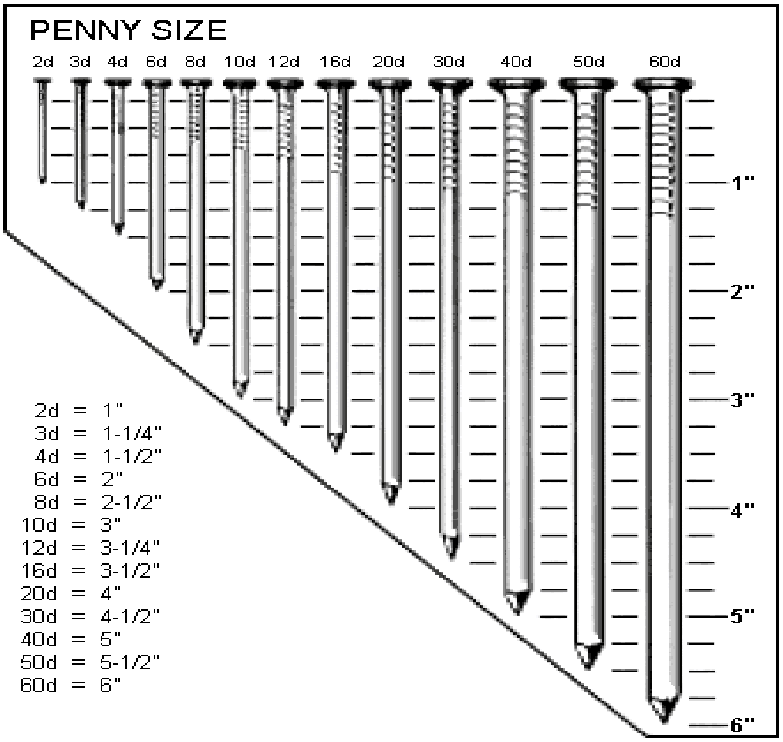

Figure 20.4 - Nail Length Chart

Wood screws or deck screws used on trail structures should be hot-dipped galvanized or stainless steel to prevent corrosion and increase longevity. The screw heads should be either square or star drive to ease driving and removal. Figure 20.5 is provided as reference for identifying and selecting appropriate screw sizes.

20.11.5. Wire Rope

Wire rope used in non-rigging applications is pre-stretched, galvanized, and engineered for proper tensile strength. When used in barrier applications, wire rope should have a plastic coating to eliminate loose strands of wire puncturing the user's hands. Only rope of good quality and a suitable size should be used. All metal components should be rust resistant.

20.12. Paints, Sealants, and Preservatives

When appropriate, paints, sealants, and preservatives are applied to wood, as well as metal components of trail structures. Sealants and preservatives must not contain pentachlorophenol, creosote, or other restricted substances. Recommended sealant for exposed wooden structural members is boiled linseed oil, cut 50% with paint thinner and a Japan drier additive. A recommended preservative for non-exposed wooden components is copper naphthenate. A wood preservative is not advised unless warranted by insect or fungi infestations. Preservatives can be avoided through the use of con heart redwood or cedar, prevention of earth to wood contact, and/or by providing a proper air gap.

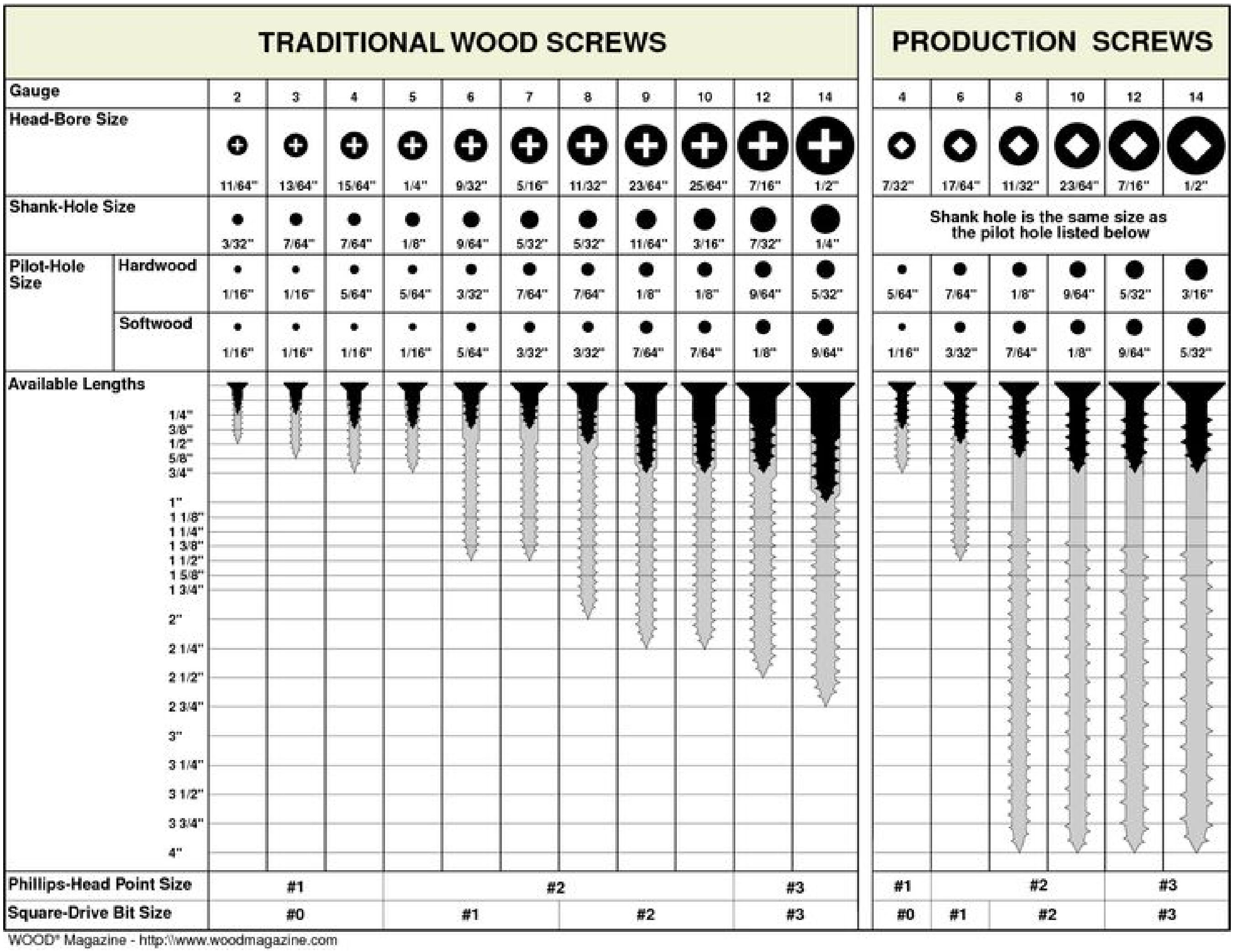

Figure 20.5 - Wood Screw Chart

In recent years a number of non-toxic wood preservatives have become available. Some of the more promising products are internal wood stabilizers. These are clear liquids that when applied to bare wood have a chemical reaction with the free alkalis that exist naturally in wood. When the liquid and alkali meet, a waterproof gel forms within the pores of the wood. Over time, that gel hardens to silicate glass crystals, which harden and densify, preventing the wood from absorbing water, reducing the chance of rot, and increasing the longevity of the wood. The glass crystals remain permanently imbedded deep within the wood. Note, this product does not contain UV inhibitors, so the wood will eventually turn silver in color if exposed to sunlight. It can also push excess tannin out of the wood as the crystals form, turning the wood very dark or even black if it is redwood.

Metal primers and paints must not contain lead or other restricted substances. A recommended primer for ferrous metals is a red oxide, synthetic, alkyd-based industrial primer. A recommended finish is synthetic alkyd-based enamel. The use of metal primer and paint should be avoided on trail structures if possible as they require cyclical re-application. On large structures such as bridges, re-application may require sand blasting. Control agencies typically require that all sand and material removed by sand blasting be captured, which can be very expensive. Pre-galvanized metal or all weather steel do not require primer and paint and therefore have lower long-term maintenance costs.

20.13. Fiber Reinforced Plastic

On trails, the primary use of fiber-reinforced plastic (FRP) is in the construction of bridges including I beam stringers and associated channels (diaphragms). It is also used in the fabrication of pony truss bridges. FRP (also called fiber-reinforced polymer) is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, aramid, or basalt. The polymer is usually an epoxy, vinylester, or polyester thermosetting plastic, though phenol formaldehyde resins are still in use.

These lightweight and corrosion-resistant I beams are ideal for bridges in coastal environments. They also are a good solution for bridges located in areas that are difficult to access because they are lightweight and therefore easier to transport out the trail than other materials. FRP I beams have a limited span length (30 feet maximum) due to the lower tensile strength of this material. They are not fire- or ultraviolet light-resistant. They can be ordered in a variety of colors but dark grey, charcoal, or black are the least obtrusive. Placing them in shaded locations and increasing the decking overhang can mitigate ultraviolet light concerns.

The pony truss FRP bridges are manufactured and sold as a complete bridge package. They are also a good design for bridges located in a coastal environment. These bridges are manufactured in lengths up to 100 feet. They are lightweight, easy to transport out the trail, and do not require a lot of skill to assemble. Some of these pre-manufactured bridges are only rated to 80 pounds per square foot live load, so their load rating must be verified prior to purchase. Seismic, wind shear, and snow load rating requirements must also be provided to the manufacture.

20.14. Geosynthetic Materials

20.14.1. Geotextiles

A “geotextile” is typically defined as any manufactured material used to increase soil stability, provide erosion control, and/or aid in drainage. Modern geotextiles are usually made from synthetic polymers, such as polypropylene, polyester, polyethylene, and polyamides. Geotextiles can be woven, knitted, or non-woven. Varying polymers and manufacturing processes result in an array of geotextiles suitable for a variety of civil construction applications.

20.14.1.1. Non-Woven Geotextiles

Non-woven geotextiles resemble felt and provide horizontal water flow. They are commonly known as “filter fabrics,” although woven monofilament geotextiles can also be referred to this way. Typical applications for non-woven geotextiles include aggregate drains and erosion control.

20.14.1.2. Woven Geotextiles

A woven geotextile is a planar (flat and two dimensional) material produced by interlacing two or more sets of strands at right angles. There are two types of strands: slit films, which are flat, and monofilaments, which are round. Woven slit-film geotextiles are generally preferred for applications where strength is needed but filtration is less critical. These fabrics reduce localized shear failure in weak subsoil conditions and aid in construction over soft subsoils.

Geotextile-related materials, such as fabrics formed into mats, webs, nets, grids, or formed plastic sheets, are not the same as geotextiles. These materials fall under the more general category of “geosynthetics.”

Since their introduction in road construction, geotextile fabrics have also demonstrated usefulness in trail construction and maintenance. Geotextiles are manufactured using a variety of fabrics, materials, and styles. This growing industry introduces new products each year that are developed to improve or expand their applications. Geotextiles are used in trail hardening, drainage structures, retaining walls, and erosion control. (See Chapter 8, *Accessible Trail Design*, Chapter 11, *Principles of Trail Construction*, Chapter 13, *Retaining Structures*, Chapter 14, *Drainage Structures*, and Chapter 27, *Trail Removal and Site Restoration*.)

When considering the use of geotextile fabrics, contact a reputable manufacturer or supplier to get advice on which fabrics they recommend for a particular application.

20.14.2. <u>Cellular Confinement</u>

Cellular confinement is a lightweight non-native material that consists of cells similar to honeycombs. (See Chapter 13, *Retaining Structures*.) This material is used similarly to geotextile fabric, but cellular confinement is stronger and able to withstand greater lateral and directional force. Cellular confinement can be used in a variety of ways. In this handbook, it is used for the construction of retaining structures. Cellular confinement comes in a variety of colors, strengths, widths, lengths, and heights. When filled with compacted soil or aggregate, a cellular confinement retaining wall creates individual cells with enhanced mechanical and geotechnical properties. The honeycomb design of the cells increases the shear strength of the confined soil, which creates a stiffer and more stable foundation and increases shear resistance and load bearing capacity.

Cells of 3 to 8 inches in height are available. Six- and 8-inch high cells are most commonly used for retaining walls. Most manufacturers produce geocell units 8 to 10 feet wide and 13 to 66 feet long. These units can be widened or lengthened by stapling two or more units together. Some manufacturers also provide clips to unitize individual units. Cell units can also be narrowed or shortened by cutting the cells outside of the welded seems. Perforated cells are also available when drainage through the retaining wall is required. Some manufacturers provide tendons, anchor rods, or metal anchor strips to strengthen retaining walls.

20.14.3. Trail Hardening with Porous Pavement Panels

Where a trail traverses through chronically wet and unstable soil and rerouting the trail to a more sustainable alignment is not an option, the installation of porous pavement panels may be a viable solution to reduce trail degradation and environmental impacts. Porous pavement panels are three dimensional, open grid, structural geotextiles designed to provide a durable wear surface and load distribution. These panels are installed over a prepared sub-base and filled with soil. They facilitate water passage and grass growth through the grids in the panels. Where sub-soils are weak, unstable geotextile fabric is installed under the panels to provide additional support. There are several commercial porous pavement products available. These panels are light weight, easy to assemble, and require a minimum number of tools and equipment.

Some of the best documented uses of porous pavement panels have been in Alaska where off-highway vehicle use is common on wet and unstable soil. The use of these panels could also be applied to mountain bike and pedestrian trails. The open grid design makes these panels unsuitable for equestrian use. For further information on porous pavement panels refer to the U.S. Forest Service’s publication “Managing Degraded Off-Highway Vehicle Trails in Wet, Unstable, and Sensitive Environments”.

20.15. Culvert Materials

Culverts are constructed of corrugated steel, aluminum, acrylonitrile butadiene styrene (ABS), concrete pipe, rock, or wood. Each material has its own advantages depending on the application.

20.15.1. Corrugated Metal Pipe (CMP) Culverts

CMP is constructed of corrugated galvanized steel or aluminum alloy. The corrugations (ribbing) are annular or helical. For trail applications, the wall thickness of corrugated metal pipe should be a minimum of 16 gauge. Metal culverts are strong, durable, and comparatively inexpensive. When used properly, they can last between 25 and 40 years. The bottom and sides are subject to abrasion when used on watercourses that transport aggregate, which can lead to a shorter life expectancy. The ribs project above the culvert wall and are struck by the aggregate as it is carried through, especially in an aluminum culvert, which is a softer and more easily abraded metal. Steel culverts are more fire resistant and less apt to burn or melt in a wildfire than aluminum culverts, but are heavier and more difficult to transport. Due to salt corrosion in coastal environments, galvanized steel culverts have a shorter life span than aluminum. Both galvanized steel and aluminum culverts come in round and oval shapes. Oval-shaped pipes are desirable when a large diameter is required but difficult to install in locations where the required dip at the crossing and minimum fill required over the culvert can’t otherwise be achieved. An oval culvert has a greater capacity and less pipe height than a round culvert, making it ideal in these situations.

20.15.2. Acrylonitrile-Butadiene-Styrene (ABS) Culverts

ABS culverts, often referred to as plastic culverts, are lighter in weight and more flexible than metal culverts, and available in single- and double-walled forms. The life expectancy is unknown, since they have not been in use as long as metal culverts. If properly located and installed, the longevity may be equal to that of metal culverts. The exterior of single- and double-walled culverts is corrugated and similar to annular corrugated metal culverts. Single-walled ABS culverts are very lightweight and easy to cut, shape, and transport. Due to the corrugated interior, the pipe is also subject to abrasion when used on streams that transport aggregate. Double-walled culverts have an additional wall inside the corrugation, which gives the inside of the pipe a smooth appearance. The advantage of a double-walled culvert is added strength, added ability to efficiently transport water, aggregate, and debris, and resistance to abrasion. Disadvantages include increased weight and decreased flexibility. Lack of corrugation on the inside wall can also result in a higher velocity flow, which can make the discharge from the culvert more erosive if an appropriately designed energy dissipater is not provided. A higher velocity may also impede the upstream movement of fish and amphibians through the culvert. ABS culverts are not fire resistant and burn or melt at a very low temperature when compared to metal culverts. ABS culverts are supposed to be UV resistant, but experience has shown that these culverts will degrade quickly when exposed to direct sunlight.

20.15.3. Concrete Culverts

Concrete culverts in trail applications are rare due to the heavy weight, lack of flexibility, and difficulty in transporting. They are appropriate near a trailhead where vehicular support is available. Concrete is very durable and the smooth walls of the pipe’s interior give it similar performance to the double-walled ABS culvert. When properly located and installed, these culverts last between 40 and 100 years. Concrete culverts do not burn but will fracture and crumble when exposed to intense heat. This type of culvert is installed in short sections (approximately 4 feet long) due to the heavy weight. The major drawback is the likelihood of failure at the joints between sections. This failure can occur with ground swelling, ground settling/movement, or root intrusions. Failed joints leak water, which erodes the material around the culvert.