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Chapter 16. Trail Bridges

A trail bridge is a structure along a trail that spans over a waterway, precipitous slope, or other unstable ground that cannot support trail construction. Typically, a trail bridge is longer than a single span puncheon or boardwalk. If the height from the deck of the bridge to the ground or watercourse channel below is 48 inches or more, railings are required for safety. In addition to horizontal railings, a mid-rail or diagonal mid-rail is also necessary for edge protection.

16.1. Bridge Site Evaluation

Bridges are expensive to build and maintain. They also can have significant impacts to park aesthetics and resources. Before deciding to build a bridge, consider other crossing designs first. (See Chapter 14, *Drainage Structures*, and Chapter 15, *Timber Planking, Puncheons, and Boardwalks*.)

Bridge sites represent major control points designed within a trail alignment. The process and some of the criteria for identifying the most appropriate location for these sites are discussed in Chapter 5, *Principles of Trail Layout and Design*, and Chapter 14, *Drainage Structures*. A brief summary of those criteria are listed below:

- Narrow channel width to reduce bridge span;
- Straight channel to reduce bank erosion;
- Stable watershed to reduce stream bed aggradation or channel scour;
- Stable banks to provide a long term foundation for bridge abutments; and
- High banks to place bridge elevation above high water flow and associated floating debris projecting above flood waters.

In addition to those criteria, there are other factors that should be considered when selecting a bridge site. The first thing to consider is the proximity of the bridge site to the overall trail corridor. Evaluate several potential bridge crossing sites; some may require substantially more trail construction and create more resource impacts than other sites. Even if a site has good physical attributes, the feasibility, cost, or resource impacts of building the trail to the site might eliminate it from consideration.

The length of the bridge span is another factor to consider when selecting a bridge site. Selecting a site with a short span increases the options for bridge design and materials selection. It also potentially reduces resource impacts, improves aesthetics, minimizes material transportation, and reduces construction and maintenance costs. When identifying the required bridge length, identify both the “free span” and the “total span.” The “free span” is the length of the bridge stringer that is not supported by the abutment sills. It is the distance between the fronts of the abutment sills on which the stringers will lie. This portion of each stringer is not supported from below and carries the full weight of bridge. The “total span” includes the “free span” as well as those portions of the stringers that are resting on the abutment sills. This length will vary depending on the abutment sill design (e.g. number of sills used and the width of the sills). Both the

free span and total span are needed to calculate the load bearing capacity of the stringers and the abutment sills.

Access to the site is another concern. Bridge stringers, along with abutment and superstructure materials, will need to be transported to the bridge site. Generally, this transport is via hand carrying, pushing or pulling bridge components attached to trail carts or other wheeled carriers, or high lead and/or skyline rigging. These methods can be tremendously time and labor intensive, especially if the distance to be traversed is great or the ground is difficult. If site conditions and land management policies permit, helicopters can be used to transport stringers, but with hourly costs in the thousands of dollars, it can be expensive.

Other desirable features of a bridge crossing site might include appropriately sized and located trees, large boulders, or bedrock outcrops that can serve as high anchor points. Anchors are essential for securing a high lead or skyline rigging that may be required to transport, place, and assemble the bridge.

Bridges often serve as a focal point for trail users. People usually stop on these structures and contemplate their surroundings. Selecting a crossing site that provides pleasing views of the stream or vistas of the surrounding countryside can have a dramatic impact on the user's experience. Crossing locations with these attributes combined with a bridge design that complements or enhances the natural setting should be the goal of every trail designer. How a bridge fits into the natural setting can be either a positive or negative attribute.

Bridges are usually located within the inner gorge of a watershed. The inner gorges of most watersheds are inherently dynamic and unstable. Building a bridge in these locations requires careful examination of the site. Geomorphic features, such as landslides, debris flows, or scarps, are obvious indicators of instability. More subtle indicators of instability include pistol grip trees that are symptomatic of slow earth movement due to land creep, or trees tilting in various directions that are indicative of more rapid earth movement. (See Photo 16.1.) Note, pistol grip trees also result from snow loading on the uphill side of the tree. The bend at the base of these trees should not be confused with slope instability. (See Photo 16.1.) Sudden openings in the forest canopy may be an indication of past landslide activity. Areas exhibiting these attributes should be avoided as they may lead to the failure of the bridge or the approaching trail alignment.



Photo 16.1 - “Tilted” (left) & “Pistol Grip” (right) Trees Caused by Slope Instability

It is always desirable to support abutments on bedrock. When bedrock is not possible, evaluate the substratum intended to support the bridge for structural integrity, water intrusion, and saturation. Saturated or loose, unconsolidated soil may not provide suitable support for a bridge abutment. Weak soil may require some type of retaining structure to become a suitable foundation. However, before entertaining construction of a retaining wall to contain abutment materials, the potential effect of the wall on the hydrology and morphology of the stream has to be carefully evaluated. Sites with weak or unstable substratum should be avoided.

During reconnaissance of potential bridge sites, obtain several key measurements that will ultimately influence the selection of the bridge location and design. The length of the bridge as previously discussed is critical in assessing project logistics, bridge design, project impacts, construction costs, and future maintenance and replacement costs. The initial bridge span estimate can be quickly obtained using a laser range finder. Most of these measuring devices are accurate within 1 meter. Although this degree of accuracy is not sufficient for developing bridge construction plans, it should be sufficient for the first reconnaissance.

At some point someone must cross the watercourse to evaluate both banks of the bridge site. With two people, a cloth or steel tape measure can be used to obtain bridge span measurements that are accurate within fractions of an inch. When taking measurements, be sure that the ends of the bridge (points being measured) on both banks are far enough from the edge of the bank that potential adjustments to the bank will not compromise the bridge. The set-back distance will be site specific. If the five

bridge site selection criteria discussed above are used to evaluate and select a bridge site, determining the additional bridge length required to achieve sufficient set back from the edge of the bank should be easily deduced. If in doubt about the proper set back, consult with a qualified hydrologist or engineering geologist.

When discussing the banks of a water course, use the orientation method developed by hydrologists. Simply put, refer to the banks based on the perspective of facing downstream. Thus, when facing downstream, the bank on the left side of the watercourse is the “left bank” and the bank on the right side it is the “right bank.” Maintaining this orientation will ensure that all future communications regarding the bridge site will be clearly understood by the designers and the trail crew.

In addition to measuring the span of the bridge, determine the elevation difference between the right and left banks. This measurement can be accomplished using one of two simple field methods. Both methods require two individuals who have already established horizontal reference points on each other as discussed in Chapter 5, *Principles of Trail Design and Layout*. Standing on opposite banks at the locations identified as the ends of the bridge, the two individuals sight on each other using clinometers or Abney hand levels. If the instruments both read zero, the two locations are roughly level to each other. If one side is higher than the other, the lower side will have a positive percent reading and the higher side will have a negative percent reading. These two readings should be accurate if they are within half a percent of each other. To determine the elevation difference between the two banks, multiply the distance between the two banks by the percentage of the largest clinometer or Abney hand level reading. For example, if the low side reading is +3% and the high side reading is -3.5%, and the span between these two locations is 30 feet, the elevation difference is 1.05 feet ($30 \text{ ft.} \times 0.035 = 1.05 \text{ ft.}$). (See Figure 16.1.)

The second field method for determining elevation differences between the banks is for the two individuals to sight on each other to determine if they are level. If one side is lower than the other then the person on the lower side holds a locking tape measure up against their body part that is the reference point for the other person (e.g., upper lip). Place the tape measure so the point where the blade of the tape measure enters the body of the tape measure is level to the reference point (e.g., the person’s upper lip). They then slowly run the blade up until the end of the tape measure is level (i.e., at zero percent) to the person sighting on it. Then they lock the tape measure and look at the length of the tape. This reading should be the elevation difference between the two locations. (Figure 16.1.)

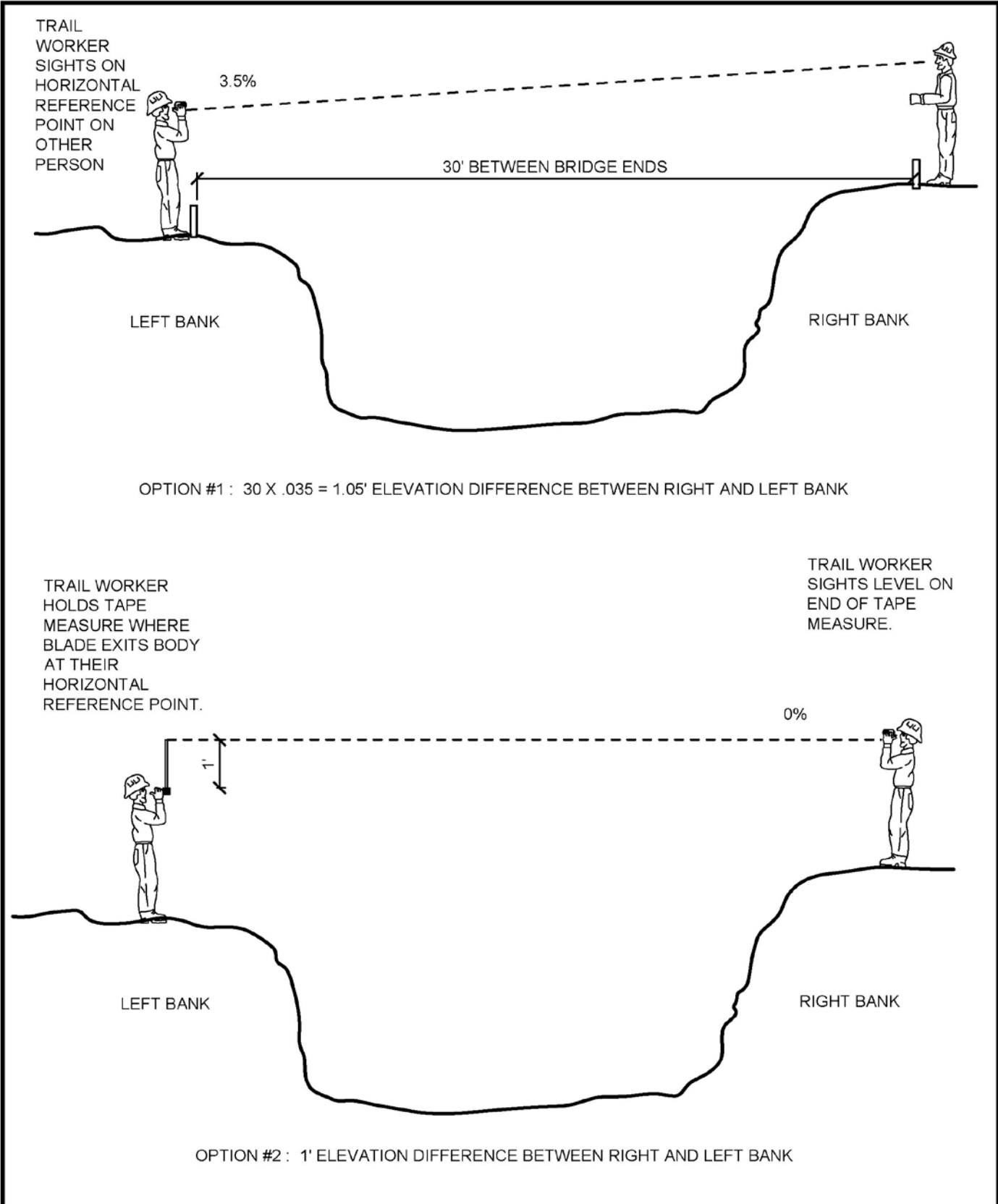


Figure 16.1 - Determining Bank Elevations



DETERMINING BANK ELEVATIONS
CALIFORNIA STATE PARKS

NOT TO SCALE

If one bank is lower than the other, level the two sites by excavating the higher bank down, elevating the lower bank with a retaining structure, or using a combination of both methods. This decision is influenced by several factors:

1. The elevation of future high flows: The elevation of the higher bank may be required to obtain the necessary freeboard (i.e. distance from the bottom of the bridge stringers to highest expected water elevation and floating debris).
2. The difficulty and cost of excavating the higher bank: The bank may be solid bedrock making it more costly to excavate than to raise the other bank.
3. Depth of the bedrock: Solid bedrock is a very desirable foundation for a bridge. However, the stability of a shallow bed rock formation may be compromised by a deep excavation.
4. The difficulty and cost of constructing a retaining structure to elevate the lower bank: Depending on the availability of native materials, the cost of buying and transporting materials, project complexity, and labor costs, it might be more cost effective to lower the higher bank.
5. The influence of the approaching trail alignment: The elevation and linear grade of the approaching trail alignment might benefit by raising or lowering the bridge site.
6. The potential for resource impacts with either method: Depending on the site conditions, one method may have less resource impacts than the other.

Another measurement that should be determined is the height of the bridge at its deck. This measurement should include the height of the retaining structure abutment (if used), sill (if used), beam seat bracket, bridge stringer, and decking. For example, a 30-foot milled stringer bridge may include mudsills of 14 inches, a beam seat bracket of 1/2 inch, a Douglas fir bridge stringer of 16 inches, and decking of 3 inches. In this example, if a rock retaining wall of 12 inches is required on the left bank, the left bank side of the bridge is 45 1/2 inches above ground ($12 + 14 + 1/2 + 16 + 3 = 45 \frac{1}{2}$ in.) and the right bank side of the bridge is 33 1/2 inches above ground ($14 + 1/2 + 16 + 3 = 33 \frac{1}{2}$ in.) since no retaining wall is required on this side.

These measurements are also important to determine the elevation of the trail alignments approaching each side of the bridge. If the starting elevation of the trail is to be the finished bridge height then the layout of the trail must start at the bridge deck elevation. One person stands at the bridge site on the left bank at approximately the starting elevation of the abutment. It may be necessary to excavate out loose organic material and topsoil so the worker is standing on mineral soil. Lock the tape measure at the desired finished height of the bridge (e.g., 45 1/2 in.). Then hold the tape measure up against the body part that is the reference point for the other person. Keeping the tape measure plumb, place it so the point where the blade of the tape measure enters the body of the tape measure is level to the reference point. The second person then steps onto the approaching hillside and uses a clinometer or Abney hand level to sight on the top of the tape measure blade. The second person adjusts their elevation on the hillslope until it is level with the top of the tape. The elevation of their feet is where the approaching trail grade begins. (See Figure 16.2.) Perform this same task on the right

bank. Once completed, the approaching trail grades are anchored to the finished bridge height.

Ensure that the approaching trail grade is within the design standards and avoid sudden grade changes by identifying the finished elevation of the bridge deck. Keeping the approaching trail elevation the same as the deck elevation eliminates the need for steps, improving accessibility and use by equestrians and bicyclists.

If steps are prescribed then follow the step layout and construction processes described in Chapter 17, *Step Construction*.

The need for a bridge approach structure, its size, complexity, and cost need to be factored into the decisions concerning bridge location, span, and design. Depending on the topography of the trail approaches, a retaining structure or short bridge span may be required to facilitate the joining of the bridge and the trail.

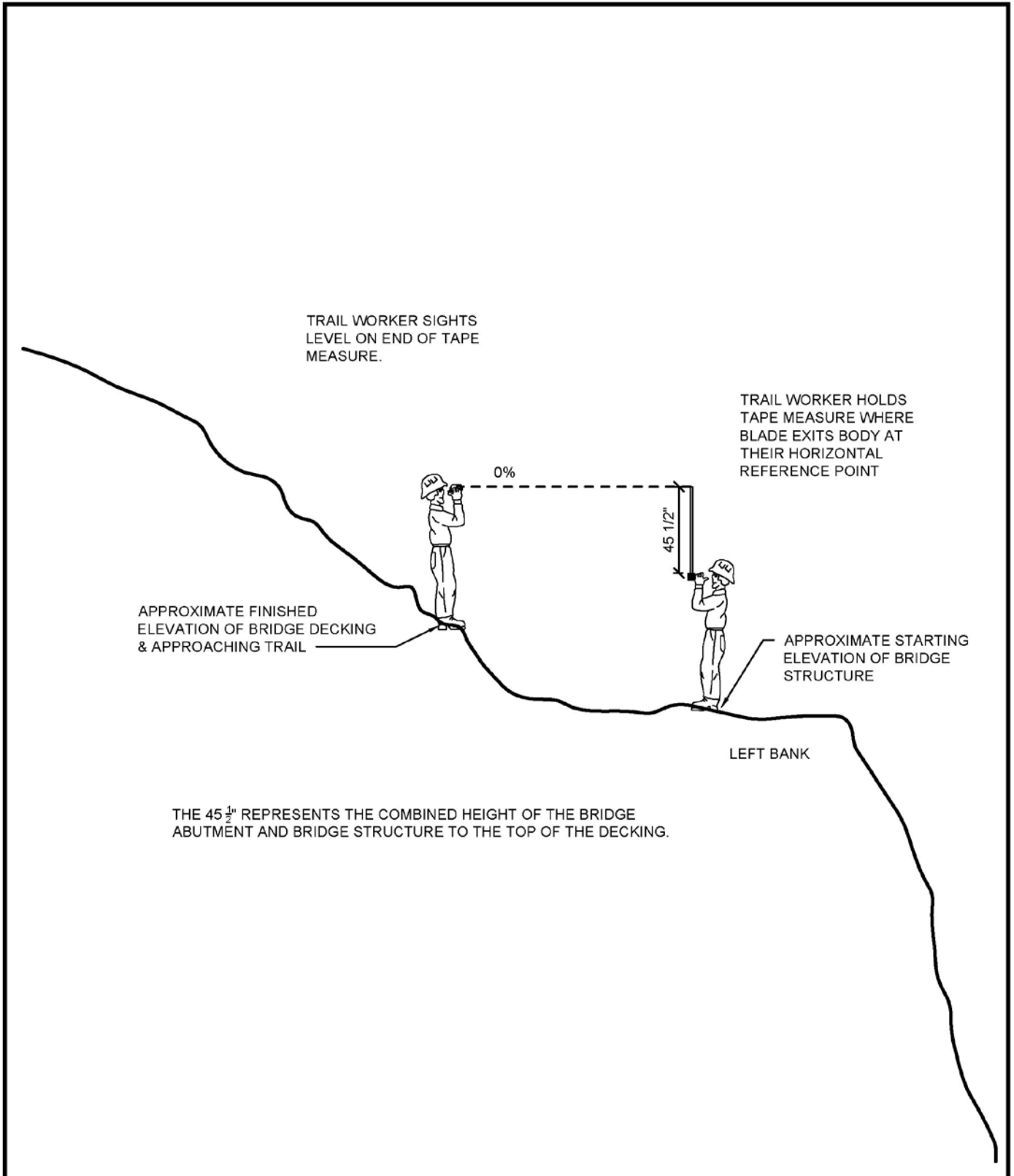
Once all potential bridge sites are thoroughly evaluated and the most appropriate site and required span are selected, identify the type of bridge design that best fits the project.

16.2. Selecting a Bridge Design

Using all the information developed during the bridge site assessments, select a bridge design that is the most appropriate for the site conditions, trail standards, user types, and management policies. Regardless of the chosen design, it must be properly engineered to be considered safe for public use. The design must accommodate the Department's minimum live load rating (100 pounds per square foot), dead load (weight of the bridge's superstructure), snow load (maximum anticipated snow fall on the bridge), wind shear (wind force against the bridge), and seismic conditions (level of seismic activity in the geographic area of the bridge). The ability of a bridge to accommodate these engineering requirements is dependent on the design of the bridge and the materials used to construct it. A variety of designs, required materials, and their relative merits and limitations are discussed below.

Note, the log, milled wood, and laminated wood ("glulam") bridge stringer charts in this chapter were developed by licensed engineers to meet the minimum live weight load rating of 100 pounds per square foot, as well as the dead load rating associated with the railing and decking designs in this chapter. These bridge stringer charts do not account for snow load, or seismic or wind shear conditions. A bridge that exceeds the lengths in these charts or the dead load weights of these drawings must be designed and stamped by an appropriately licensed structural engineer.

In Appendix I there are examples of working drawings that have been approved for use by the Department for most of the bridge designs discussed below. Other agencies should review and approve these drawings prior to use.



TRAIL WORKER SIGHTS
LEVEL ON END OF TAPE
MEASURE.

TRAIL WORKER HOLDS
TAPE MEASURE WHERE
BLADE EXITS BODY AT
THEIR HORIZONTAL
REFERENCE POINT

0%

45 1/2"

APPROXIMATE FINISHED
ELEVATION OF BRIDGE DECKING
& APPROACHING TRAIL

APPROXIMATE STARTING
ELEVATION OF BRIDGE
STRUCTURE

LEFT BANK

THE 45 1/2" REPRESENTS THE COMBINED HEIGHT OF THE BRIDGE
ABUTMENT AND BRIDGE STRUCTURE TO THE TOP OF THE DECKING.

Figure 16.2 - Determining Approaching Trail Grade



DETERMINING APPROACHING TRAIL GRADE

CALIFORNIA STATE PARKS

NOT TO SCALE

16.2.1. Log Stringer Bridge

16.2.1.1. Applications

The log stringer bridge is one of the most basic trail bridge designs. (See Photo 16.2). It consists of mudsills, log stringers, post sills (as required), decking, soil dams, posts, and railings (as required). The materials for this structure are often produced on-site. The stringers, mudsills, post sills, decking, soil dams, posts, and railings are sawn or split from felled or downed trees. The harvesting of trees or downed logs for use on trail structures must be supported by the project's environmental review.

16.2.1.2. Attributes

This structure is a good backcountry design that requires relatively inexpensive, on-site, native materials with a rustic appearance that fits the surrounding environment. The use of on-site native materials eliminates the cost of purchasing these materials and may be the only practical means of obtaining building materials in remote locations.



Photo 16.2 - Log Stringer Bridge

16.2.1.3. Limitations

When using downed or felled trees for bridge stringers, it can be hard to verify their structural integrity. These logs often have fractures or pockets of rotten wood that cannot be detected from the exterior. Portions of logs that have been in contact with soil or other decaying organic materials for extended periods of time and are showing signs of decay should not be used for stringers. The most effective way to reduce the risks presented by these defects is if the bridge builder selects a healthy live tree for felling, so that they know the stress the log was subjected to when it landed (preferably on a prepared bed).

Manufacturing the building materials and assembling the bridge can be labor intensive. Logs used for the stringers must be debarked, have all their sapwood removed, and allowed to dry prior to use. All joints must be custom fit and joining and leveling irregular shaped round or split stock can be time consuming. The traditional wood-working skills required to perform this work is often lacking in today's labor force.

A log stringer bridge is good for short to moderate spans of 12 to 40 feet. (Figure 16.3.) Simple rigging techniques such as high leads can be used to transport the log stringers (usually a short distance from the bridge site) and set them on the mudsills. Depending on the species of tree and the environmental conditions of the bridge site, the life span of log bridges can be limited. If the trail crew has the requisite skills and the logs are within close proximity to the bridge site, the cost of constructing this style of bridge is on average cheaper than all other bridge designs.

LOG STRINGER TABLE

Doug Fir, #1 Highline

Non-trussed Spans

Three Stringer Log Trail Bridge

Maximum Span in Feet	Small End Diameter in Inches
<12	9
>12 & <15	10
>15 & <17	10 ½
>17 & <18	11
>18 & <20	12
>20 & <22	13
>22 & <24	14
>24 & <26	15
>26 & <28	16
>28 & <30	16 ½
>30 & <32	17
>32 & <34	17 ½
>34 & <36	18
>36 & <38	18 ½
>38 & <40	19

Notes:

1. Consult with a licensed civil engineer to verify load calculations.
2. Diameters are for the small ends of the log stringers.

Figure 16.3 - Log Stringer Table

16.2.1. Milled Stringer Bridge

16.2.1.1. Applications

A milled stringer bridge is by far the most common bridge design used on trails. It consists of milled mudsills, stringers, decking, soil dams, post sills, posts, and railings. The building materials required for this structure are readily available from most lumber yards. Depending on the type of lumber and the finishing of the bridge, this structure can have a modern or rustic appearance making it suitable for both front and backcountry applications. (See Photo 16.3 and Figure 16.4.)

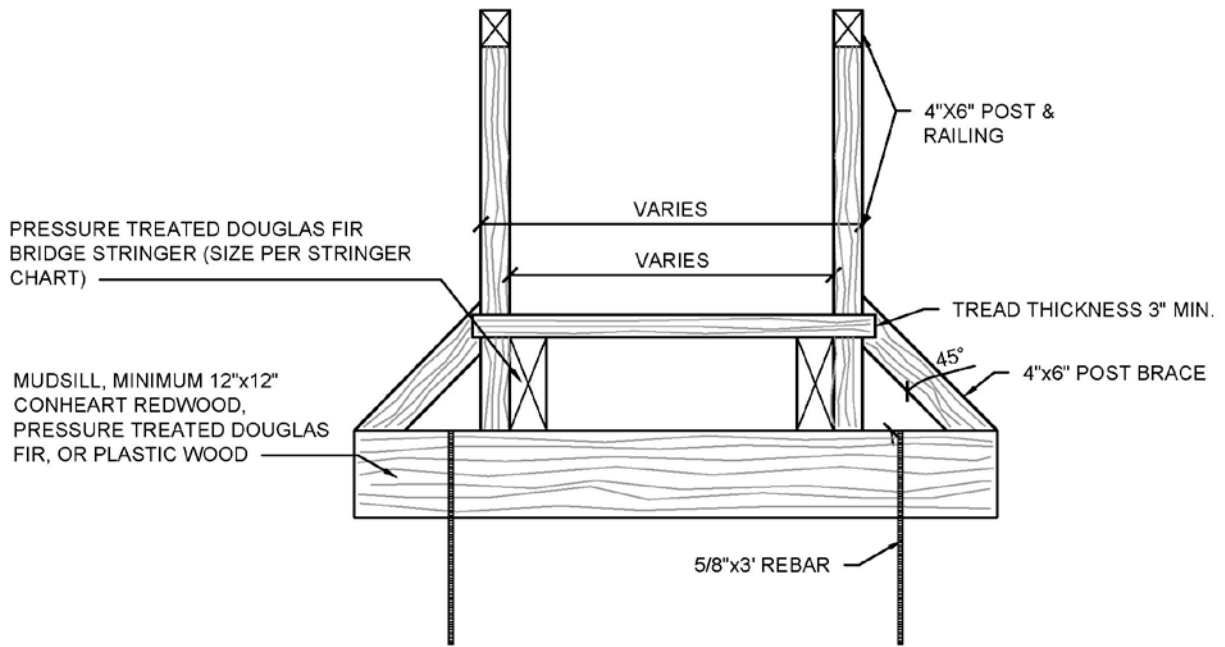


Photo 16.3 - Milled Stringer Bridge

16.2.1.2. Limitations

A pre-engineered milled stringer bridge is limited to a span of 12 to 30 feet. (Figure 16.5.) Stringers can be transported using log tongs, a wheeled cart, or rigging techniques such as high leads and sky lines. All of the other bridge components can be transported via trail carts or hand-packing. Depending on the species of lumber and the local climate, these stringers can have a short life span. Even pressure treated lumber will not last more than 15 years in cool, wet climates. Cutting and drilling through pressure treated lumber will compromise the rot-resistant treatment even if it is painted with a wood preservative. Pressure treated lumber may not be allowed in certain environments where solvents can leach into the water and soil. The cost of constructing this style of bridge is, on average, less expensive than all other non-log bridge designs.

END VIEW
(SOIL DAM INTENTIONALLY LEFT OFF THIS VIEW FOR ILLUSTRATION PURPOSES)



SIDE VIEW

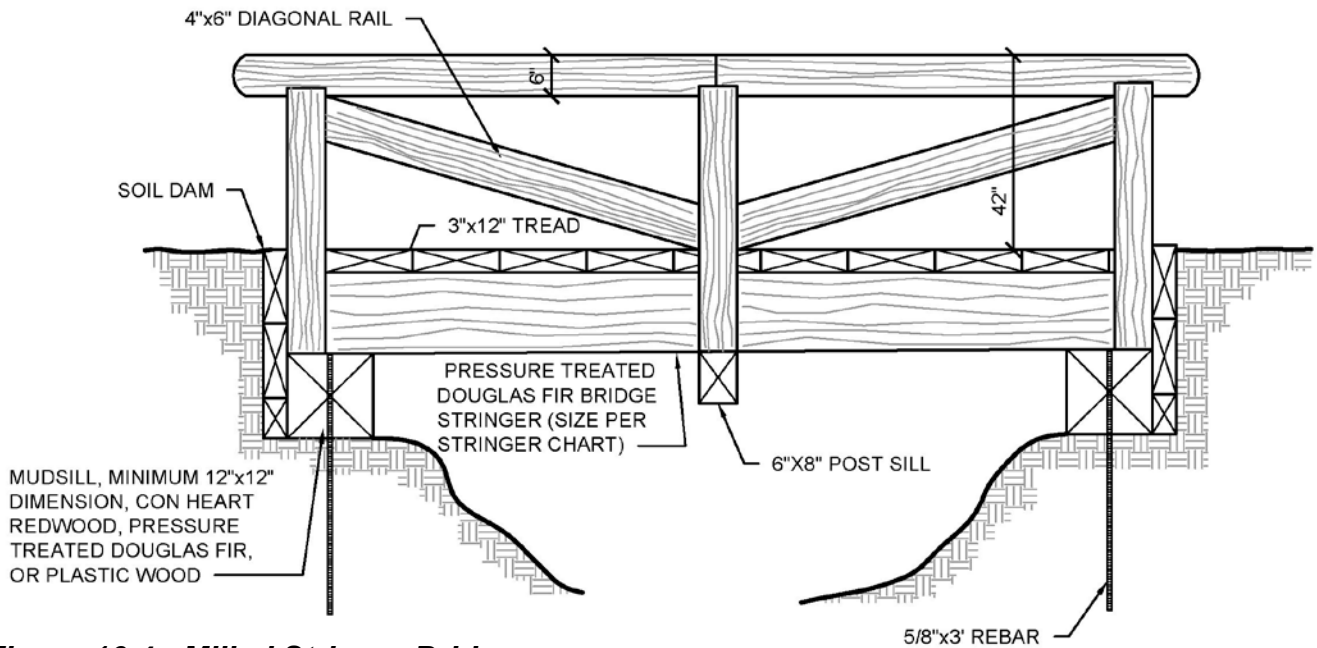


Figure 16.4 - Milled Stringer Bridge



MILLED STRINGER BRIDGE
CALIFORNIA STATE PARKS

NOT TO SCALE

MILLED & GLULAM STRINGER TABLE
Doug Fir, Select Structural, Non Treated
 Non-trussed Spans
 Two Stringer Wood Trail Bridge

Maximum Span in Feet	Stringer Dimensions in Inches
<12	6X8
>12 & <13	8X8
>13 & <15	6X10
>15 & <17	8X10
>17 & <18	6X12 or 10X10
>18 & <20	8X12
>20 & <22	6X14 or 10X12
>22 & <24	8X14 or 12X12
>24 & <25	6X16
>25 & <26	10X14
>26 & <28	8X16 or 12X14
>28 & <29	14X14
>29 & <30	10X16
>30 & <32	6.75X18 Glulam Stringer
>32 & <34	6.75X19.5 Glulam Stringer
>34 & <37	6.75X21 Glulam Stringer
>37 & <40	6.75X22.2 Glulam Stringer

Notes:

1. Maximum stock length for non-glulam stringer is 30 feet.
2. Stringer lengths over 30 feet require glulam stringers.
3. Consult with a licensed civil engineer for complex or long trail bridges.

Figure 16.5 - Milled Stringer Bridge Table

16.2.2. Glue-Laminated (Glulam) Stringer Bridge

16.2.2.1. Applications

The lamination process used to fabricate the stringers for a glue-laminated (“glulam”) bridge creates a stronger member that allows for a longer bridge span. The bridge consists of mudsills, stringers, diaphragms, sway braces, decking, soil dams, posts, and railings. They also have a semi-rustic appearance that makes them applicable in both front and backcountry settings. These are the most common bridge stringers used in mid- to long-span trail bridges. (See Photo 16.4.)



Photo 16.4 - Glulam Stringer Bridge

16.2.2.2. Attributes

A glulam stringer bridge has attributes similar to a milled stringer bridge except it can obtain spans of over 100 feet in length. It can be ordered with a Kevlar reinforcement laminate that adds strength to the stringer and reduces the stringer dimensions. A glulam stringer bridge is easy to assemble and can be ordered with an engineered load capacity. The glulam stringer bridge can be ordered so that most of the bridge hardware and lumber attachments can be bolted to the stringers, reducing the need for drilling, cutting, and fitting in the field.

16.2.2.3. Limitations

Although glulam beams or stringers can be ordered from the local lumber company using the pre-engineered stringer chart, they are only good for spans up to 40 feet. (See Figure 16.6.) It should be noted that the structural integrity and life expectancy of a glulam stringer may be compromised if holes are drilled through it to attach diaphragms, beam seats, or posts.

Glulam stringers can be purchased in lengths between 30 and 100 feet and should be purchased through a manufacturer with a licensed engineer. Provide the manufacturer with a set of bridge assembly plans that identify the dimensions and species of lumber to be used. These plans should also note where pre-drilled holes are required to attach the bridge components. This note is especially important when ordering pressure-treated glulam stringers, because these holes need to be pressure treated with the rest of the stringer.

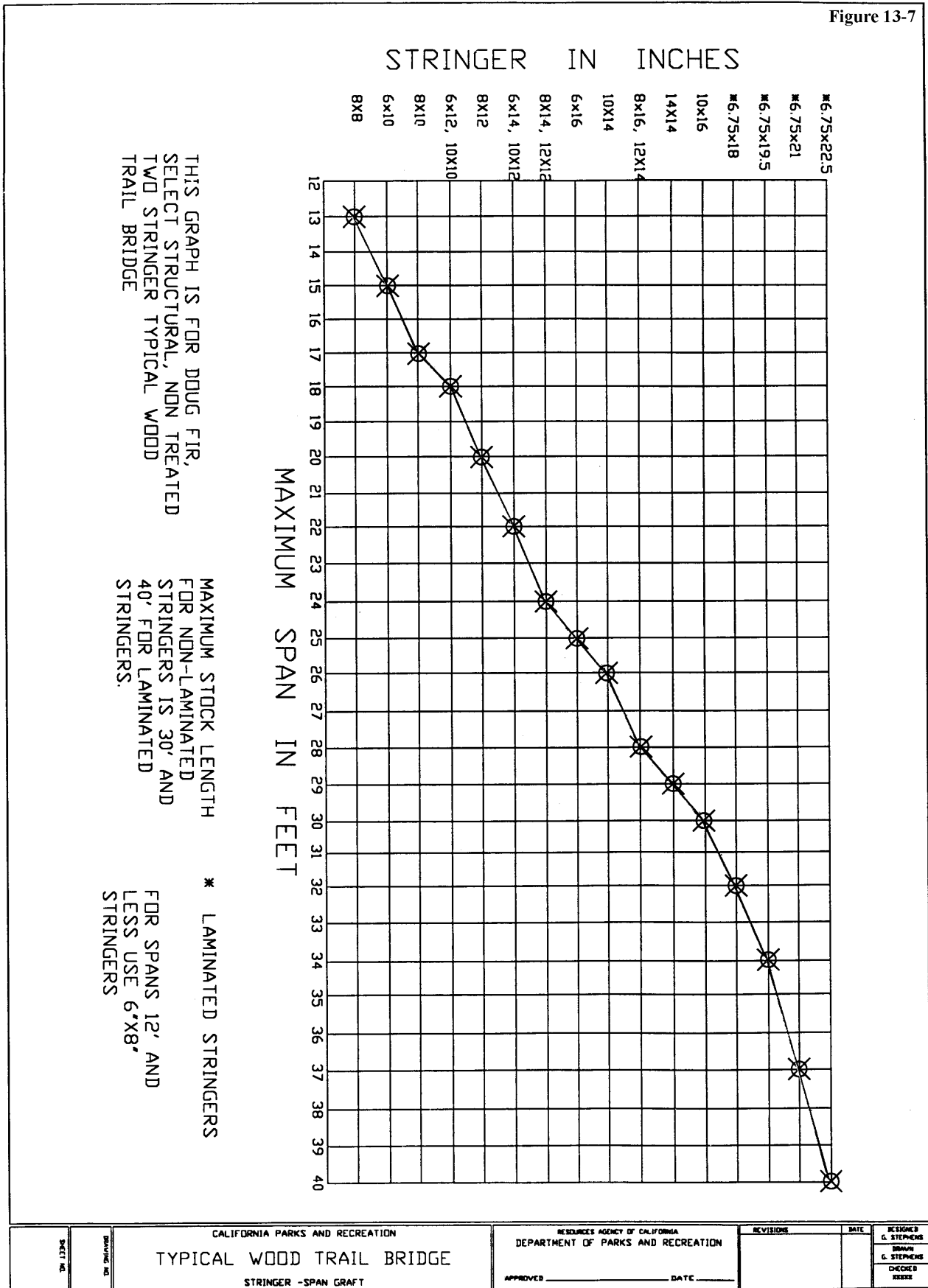
There are very few companies that are capable of pressure-treating glulam beams in excess of 50 feet and orders can take up to six months for delivery. Long span glulam beams are heavy and can be difficult to transport both on the highway and through the woods. Short span stringers can be transported using log tongs (attached to stringers with nylon straps), a wheeled cart, or rigging techniques such as high leads and sky lines. All of the other bridge components can be transported via stock, trail carts, or hand packing. Mid- to long-span stringers must be transported out the trail via a skyline or helicopter. Large stringers, which can be up to 5 feet in height, can be visually obtrusive. The cost of constructing this style of bridge is on average more expensive than log or milled stringer bridges but less expensive than steel I beam, steel truss, fiber reinforced plastic I beam, fiber reinforced plastic pony truss, and suspension bridges.

16.2.2.4. Drop Down Deck Design

Glulam bridge stringers can be designed so the decking is attached to angled iron brackets bolted to the inside bottom of the stringers. This “drop down” deck design can be less visually obtrusive than a long-span glulam stringer bridge because of the lower visual profile. Since the public can come into contact with the toxic chemicals of glulam beams, pressure treated stringers require facing with non-treated materials. Rot-resistant wood such as Alaskan yellow cedar may be a better choice for a wood laminate as it possesses good structural strength, a beautiful finished appearance, and does not require wood preservatives, and, therefore, can be exposed to the public. (See Photo 16.5.)



Photo 16.5 - Drop Down Deck Design



SHEET NO.	DRAWING NO.	CALIFORNIA PARKS AND RECREATION TYPICAL WOOD TRAIL BRIDGE STRINGER - SPAN GRAFT	RESOURCES AGENCY OF CALIFORNIA DEPARTMENT OF PARKS AND RECREATION	REVISIONS _____ _____	DATE _____	DESIGNER G. STEPHENS DRAWN G. STEPHENS CHECKED _____ _____
			APPROVED _____ DATE _____			

Figure 16.6 – Milled Wood & Glulam Stringer Chart

16.2.2.5. Arched Bridge Design

A glulam arched stringer has an exaggerated camber that produces an arched appearance. This glulam bridge is most effective in carefully selected sites where it will enhance the visual setting. The semi-rustic appearance and gracefully curved support stringers can add a dramatic effect to the appearance of the bridge. The arched stringers can also provide more clearance above high water and floating debris and increased load bearing capacity. The camber of the stringers may produce a linear grade that is difficult to traverse in icy or wet conditions. It may also be in excess of accessibility standards. (See Photo 16.6.)



Photo 16.6 - Arched Bridge Design

16.2.3. Overhead Wooden Truss Bridge

16.2.3.1. Applications

An overhead truss bridge is a modification to a milled or glulam stringer bridge. It consists of mudsills, stringers, decking, soil dams, cradle, trusses, hanger rods, truss braces, post sills (as required), posts, and railings. The overhead truss design is used to increase the load bearing capacity of the stringers. (See Photo 16.7.)

16.2.3.2. Attributes

A wooden overhead truss bridge is good for short to medium spans of 12 to 50 feet. The overhead truss assembly (cradles, trusses, hanger rods, and truss braces) provides additional support to the center of the bridge stringers by transferring a portion of the load to the sills secured to the abutments. By tightening the hanger rods, the cradle is pulled upward, thereby lifting the center of the bridge. By redistributing the weight, the load bearing capacity of the

stringers is increased allowing the use of smaller dimensioned stringers, which is desirable when constructing a bridge in remote locations where transportation of materials is difficult. The building materials required for this structure are readily available from most lumber yards. Depending on the type of lumber and the finishing, this structure can have a somewhat rustic appearance, making it suitable for both front and backcountry applications.



Photo 16.7 - Overhead Wooden Truss Bridge Design

16.2.3.3. Limitations

Most agencies will require that the plans for an overhead truss bridge be designed and stamped by an appropriately licensed engineer. (See Appendix I for a sample of an overhead truss bridge design that can be reviewed, used, or modified by an engineer.) Stringers and trusses can be transported using log tongs, a wheeled cart, or rigging techniques such as high leads and sky lines. All of the other bridge components can be transported via stock, trail carts, or hand packing. The fabrication and assembly of the trusses require advanced carpentry skills, which may not be available in all trail crews. Crews may also need to use scaffolding or a skyline when assembling the trusses. The fabrication of this bridge can be simplified by pre-cutting all the truss components at the shop before packing into the field. Because trusses project above the railing, this structure can be visually obtrusive. In some locations, the visual component can be mitigated by modifying the construction of the overhead truss to a hip truss design. (See Photo 16.8.) The cost of constructing this style of bridge is on average cheaper than a glulam bridge but more expensive than a milled stringer bridge.



Photo 16.8 - Hip Truss Bridge Design

16.2.4. Hip Truss Wooden Bridge

16.2.4.1. Applications

A hip truss bridge is also a modified milled or glulam stringer bridge. It consists of mudsills, stringers, decking, soil dams, cradles, knee braces, knee brace sills, post sills (as required), posts, and railings. Like the overhead truss, the hip truss design is used to increase the load bearing capacity of the stringers. (See Appendix I.)

16.2.4.2. Attributes

A hip truss bridge is good for short to medium spans of 12 to 50 feet. The hip truss assembly (cradles, knee braces and knee brace sills) provides additional support to the center of the bridge stringers by transferring a portion of the load to the knee brace sills secured to the banks below the bridge. Prior to installing the knee braces, the center of the bridge is lifted via a skyline or hydraulic jacks to provide the desired camber to the stringers. The knee braces are then installed to retain the camber in the stringers, thereby increasing the load bearing capacity of the stringers and allowing for smaller dimensioned stringers to be used. This attribute is desirable when constructing a bridge in remote locations where transportation of materials is difficult. The building materials required for this structure are readily available from most lumber yards. Depending on the type of lumber and the finishing, this structure can have a somewhat rustic appearance, making it suitable for front or backcountry applications. Because

the truss assembly is located underneath the bridge, the profile of this bridge design is lower than an overhead truss design.

16.2.4.3. Limitations

Most agencies will require that the plans for this type of bridge be designed and stamped by an appropriately licensed engineer. Stringers and trusses can be transported using log tongs, a wheeled cart, or rigging techniques such as high leads and sky lines. All of the other bridge components can be transported via stock, trail carts, or hand packing. The fabrication and assembly of the hip truss require advanced carpentry skills that may not be available in all trail crews. The fabrication of this type of bridge can be simplified by pre-cutting all the truss components at the shop before they are packed into the field. The site conditions required for this structure limit its applications. The bridge must be elevated high enough above future high water events that the cradle and knee braces will not interfere with those flows. The banks must be stable enough to support the knee brace sills. The banks must have a face steep enough to obtain the minimum 30% angle for the knee braces. The cost of constructing this style of bridge is on average cheaper than a glulam bridge but more expensive than a milled stringer bridge.

16.2.5. All Weather Steel I Beam Bridge

16.2.5.1. Applications

An all weather steel I beam stringer bridge can be a desirable alternative to a wooden stringer bridge due to its longer lifespan and lower maintenance requirements. It is suitable for both front and backcountry use. It is important to use only all-weather steel for stringer fabrication. When exposed to air, all-weather steel quickly forms a dense oxide layer. This layer along with the corrosion resistant alloys in the steel protect the steel from corrosion, eliminating the need for labor-intensive protective coatings and the environmental hazards that go with them. Once the steel oxidizes it turns a dark rust color that blends well with the wooden superstructure. (See Photo 16.9.)

16.2.5.2. Attributes

Typical spans for this bridge range from 12 to 100 feet. Steel I beam stringers can be fabricated in varying lengths or multiple beams can be bolted together to form the desired length. The Department has developed engineered plans for all weather steel I beam bridge stringers from 20 to 60 feet in length, which can be given to steel fabricators for bid and fabrication. (See Appendix I.) Bridge spans longer than 30 feet are designed with I beam sections that are 20 feet long or less to facilitate transportation to the bridge site. Stringers can be transported using log tongs, a wheeled cart, or rigging techniques such as high leads and sky lines. Sections of I beams can be quickly bolted together and set on abutments via skyline rigging techniques. Steel plates are welded to the I beam for

attaching railing posts. Bolt holes for attaching a 4- x 6-inch wood nailer to the top of the I beam are pre-drilled by the steel manufacturer. The decking is then attached to the nailer. The decking and railing design is the same as for all other bridge designs. When not located in a coastal or chronically wet and cool environment, a steel I beam stringer will last significantly longer than a wooden stringer.



Photo 16.9 – All Weather Steel I Beam Bridge

16.2.5.3. Limitations

All weather steel requires alternating wet and dry weather to form a properly adhered protective layer. Areas that have salt-laden air, high rainfall, humidity, or persistent fog are typically not the proper environment for this kind of bridge. Federal Highway Administration Technical Advisory 5140.22 states “If the yearly average time of wetness exceeds 60%, caution should be used in the use of bare weathering steel.” Most locations in California have less than 60% wet or foggy days annually, but if the bridge is to be located in an area known to be wet or shade protected, research should be performed to determine the annual average number of days of wetness.

Industry literature recommends that all weather steel not be used within 2 kilometers (1.32 miles) of salt water. Department engineers recommend that they not be used within 2 miles of salt water. The level of chloride in the salt-laden air and its effect on the performance of all weather steel structures depends on the direction of the prevailing wind, the distance from the shore, and the topographical and environmental characteristics of the terrain. For these reasons, the weathering behavior of all weather steel structures can vary significantly from one location to another. Thus, these influences must be

factored into the use of all weather steel bridges. All weather steel performs best when it is cyclically exposed to warm, dry air. If the steel is constantly wet or covered with moist organic matter, the oxidation process will not stabilize and the steel will rust like conventional carbon steel.

A bridge that does not receive exposure to dry air is prone to continuous oxidation. The most vulnerable area is at the contact between the decking and the top of the I beams. Oxidation can be mitigated by painting the top of the I beam with a coat of rust prohibitive primer and a coat of synthetic resin paint, or by using a nailer comprised of pressure treated, composite, or plastic wood.

An annual visual inspection and associated maintenance need to be performed on all weather steel bridges to determine the condition of the steel based on the evaluation criteria. See Chapter 26, *Drainage and Structure Maintenance*, for more information.

Fasteners used to bolt all weather steel components together or to attach the superstructure to the all weather steel must be comprised of Cor-Ten X, Cor-Ten A, or stainless steel. Fasteners of dissimilar metal will corrode through electrolysis.

In certain locations, the oxidized steel finish may be visually obtrusive, but can be mitigated by overhanging the wood decking beyond the outside edge of the steel I beam by 6 inches, thereby minimizing its visibility. Steel I beams can also be visually hidden behind a wooden or log façade. Anchoring the decking to the steel I beams is usually facilitated by welding bolts to the top of the steel I beams. These bolts are vulnerable to being damaged in transit and assembly. They also may not have the longevity of the steel I beams. However, steel I beams can have pre-drilled holes used to bolt the wooden nailer to the top of the beam, eliminating the problems associated with the welded bolts.

Steel I beam stringers (other than those designs presented Appendix I) should be purchased through a manufacturer with a qualified licensed engineer. Supply the manufacturer with a set of bridge assembly plans that identify the dimensions to be used. These plans should also note where pre-drilled holes are required to attach bridge components. The all weather steel I beam bridge designs included in Appendix I have a maximum span of 60 feet and need to be fabricated by a properly licensed vendor. The cost of constructing this style of bridge on average is comparable to fiber reinforced plastic I beam and fiber reinforced plastic truss bridges and less expensive than steel truss and suspension bridges.

16.2.6. Galvanized Steel I Beam Bridge

16.2.6.1. Applications

Galvanized steel I beam bridge stringers are used when the structure will be exposed to corrosive natural elements, such as the salt air of coastal environments or chronically wet climates. (See Photo 16.10.) When selecting galvanized steel I beams and associated steel components, it is important to use only steel that has been batch hot-dip galvanized. By completely immersing the steel product in a bath (kettle) of molten zinc, batch hot dip galvanizing produces a zinc coating with superior protection than other galvanization methods.

16.2.6.2. Attributes

Similar to all weather steel I beams, typical spans for this bridge range from 12 to 100 feet. Galvanized steel I beam stringers can be fabricated in varying lengths or multiple beams can be bolted together to form the desired length. Longer bridge spans can be designed with I beams that are 20 feet long or less to facilitate transportation to the bridge site. Stringers can be transported using log tongs, a wheeled cart, or rigging techniques such as high leads and sky lines. Sections of I beams can be quickly bolted together and set on abutments via skyline rigging techniques. Steel plates are welded to the I beam for attaching railing posts. Bolt holes for attaching a 4- x 6-inch wood nailer to the top of the I beam are pre-drilled by the steel manufacturer. The decking is then attached to the nailer. The decking and railing design is the same as for all other bridge designs. (See Photo 16.10.)



Photo 16.10 – Galvanized Steel I Beam Bridge

In temperate coastal environments, the time for first maintenance of batch hot-dip galvanized steel I beams is approximately 70 years. The steel can be repaired by painting the rusted area with a zinc-rich paint or re-galvanizing the surface entirely. If maintenance is performed when needed, the service life of the steel will be dramatically increased.

16.2.6.3. Limitations

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.

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).

Similar to all weather steel I beam stringers, in certain locations the galvanized steel finish may be visually obtrusive. Its appearance can be mitigated by overhanging the wooden decking beyond the outside edge of the steel I beam by 6 inches or hidden behind a wooden or log façade. The galvanized finish can also be darkened by spraying the I beams and associated metal components with zinc phosphate. Painting should be performed at the service yard as the zinc phosphate needs to be rinsed off with water immediately after application to prevent corrosion to the galvanized surface. Since the zinc phosphate etches the galvanized surface, this treatment should be limited to those surfaces that can be seen from the trail, which are typically the outsides of the I beams. The top of the I beams should not be treated with the zinc phosphate as this surface cannot be observed and requires the greatest corrosion resistance due to the moisture trapped between the wooden nailer and the I beam.

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.

Galvanized steel I beam stringers should be purchased through a manufacturer that has a licensed engineer to design the beams and provide engineer stamped plans. Supply the manufacturer with a set of bridge assembly plans that identify the dimensions and species of lumber to be used on the bridge's superstructure. These plans should also note where pre-drilled holes are required to attach bridge components. All bolt holes must be drilled prior to the galvanization process otherwise these locations will be vulnerable to corrosion. The cost of constructing this style of bridge on average is comparable to all weather steel I

beam, fiber reinforced plastic I beam, and fiber reinforced plastic truss bridges, and less expensive than steel truss and suspension bridges.

16.2.7. Steel Truss Bridge

16.2.7.1. Applications

A steel truss bridge is commonly used in frontcountry applications at trailheads or where heavy equipment can be used to place it. Typically, this type of bridge is manufactured and sold as a fully assembled unit due to the need to have the stringers and truss assembly unitized via welding. A long span can be shipped in sections and coupled on-site. Most bridge manufacturers use all-weather steel to simplify maintenance and provide a more rustic appearance. (See Photo 16.11.)



Photo 16.11 - Steel Truss Bridge

16.2.7.2. Attributes

This type of bridge can be ordered in lengths from 50 to over 200 feet. Since it usually comes fully assembled (except for the decking and soil dams), it is less labor intensive to install than other types of bridge.

16.2.7.3. Limitations

A steel truss bridge needs to be purchased through a manufacturer that has licensed engineers who can design the structure to meet the required load capacity and site conditions. Usually there is little flexibility in architectural design. Because most metal truss bridges are pre-assembled, it requires the use of heavy equipment such as cranes or excavators to install. Thus, this type of bridge is limited to locations where it can be transported on a flatbed truck, then

picked up and placed with heavy equipment. A short span may be air lifted into place via a large helicopter. Even if this type of bridge can be delivered into the backcountry, it may not fit the setting since it can be out of character with the surrounding environment. This bridge is also not recommended for application in marine environments. The cost of constructing this style of bridge is on average more expensive than all other bridge designs.

16.2.8. Aluminum Truss Bridge

16.2.8.1. Applications

An aluminum truss bridge is used in coastal or chronically wet environments where all weather steel and wooden or glulam bridges are not suitable due to their limited life spans. The aluminum truss bridge discussed in this section is meant to augment the fiber reinforced plastic I beam bridge design, which has a maximum span of 30 feet.

16.2.8.2. Attributes

The Department has developed engineered plans for aluminum truss bridges from 30 to 60 feet in length, which can be given to bridge or aluminum product manufacturers for bid and fabrication. (See Appendix I.) The trusses are segmented with no individual segment exceeding 22 feet in length. The short length and lightness of aluminum facilitate efficient transportation to the bridge site. A truss can be transported out the trail using log tongs, a wheeled cart, or rigging techniques such as high leads and sky lines. Trusses can be quickly bolted together and set on the abutments via skyline rigging techniques. Truss segments are also easy to assemble once on-site. The aesthetic impact of an aluminum truss bridge can be minimized with a flat mill finish to the aluminum and by covering the truss assembly with 1- x 12-inch redwood fascia boards. The design also includes pre-drilled holes in the truss cords for bolting posts to the trusses and pre-drilled holes in the trusses for bolting a 4- x 6-inch nailer to install the decking. The decking and railing designs are the same as the other bridges herein.

16.2.8.3. Limitations

Due to aluminum's lower tensile strength, aluminum bridges require a truss assembly rather than I beam stringers. Most manufactured aluminum truss bridges are designed and used at marinas and have limited appeal for use as trail bridges. The Department has developed engineered plans for aluminum truss bridges that are more suitable for trail applications. These bridge designs have a maximum span of 60 feet and must be fabricated by a properly licensed vendor. This style of bridge is more expensive than an all-weather steel I beam bridge and requires more labor for assembly due to the additional redwood fascia.

16.2.9. Fiber Reinforced Plastic (Fiberglass) I Beam Bridge

16.2.9.1. Applications

An I beam stringer bridge made from fiber reinforced plastic (FRP), also known as fiberglass, can be a desirable alternative to wooden and steel stringer bridges because it is not affected by coastal or chronically wet environments, is lightweight, and has a much longer lifespan than wood. Due to its low tensile strength, use of a FRP I beam is limited to short spans. Long spans in coastal or chronically wet environments can be accommodated with an aluminum truss bridge. The FRP I beam bridge is suitable for both frontcountry and backcountry use. The I beam can be used with an all wood superstructure so that the finished appearance is nearly identical to a wooden bridge. (See Photo 16.12.)



Photo 16.12 – Fiber Reinforced Plastic I Beam Bridge

16.2.9.2. Attributes

The Department has developed engineered plans for FRP I beam bridge stringers less than or equal to 30 feet in length, which can be given to bridge manufacturers for bid and fabrication. This bridge design also utilizes a 4- x 6- inch nailer that is bolted to the top of the I beam. There are also engineered plans for low profile FRP stringers (12 inches high), which are less than or equal to 20 feet in length. This bridge design does not utilize a nailer as the decking is bolted directly to the I beam. The nailer was eliminated to lower the bridge height. (See Appendix I.) An FRP I beam stringer is lightweight and limited to a relatively short span, making it easy to transport out the trail using log tongs,

pack stock, or wheeled carts. Bolt holes for attaching bridge components can be drilled in the field, eliminating the need for the bridge manufacturer to pre-drill the I beams. Pre-manufactured brackets and clips make it easy to attach the wooden superstructure to the FRP I beam, which means it can be assembled without a highly skilled trail crew.

16.2.9.3. Limitations

FRP I beam stringers (other than the Department's designs in Appendix I) need to be purchased through a manufacturer that has a licensed engineer. Supply the manufacturer with a set of bridge assembly plans that identify the dimensions and species of lumber to be used. If using the Department's engineered bridge plans, the bridge needs to be fabricated by a qualified and properly licensed vendor. The stringers need to be kept out of direct sunlight as they will degrade when exposed to ultra violet light. Although these stringers come in a variety of colors, the beams can be visually unattractive if viewed from the side. Thus, select a setting that does not offer a side view and/or use a dark color (such as black or grey) and overhang the wooden decking outside the edge of the beam by 6 inches to minimizing its visibility. The cost of constructing this style of bridge on average is comparable to a steel I beam or FRP truss bridge and less expensive than a steel truss or suspension bridge.

16.2.10. Fiber Reinforced Plastic (Fiberglass) Pony Truss Bridge

16.2.10.1.Applications

An FRP pony truss bridge can be an alternative to a wooden or steel stringer bridge because it is lightweight and may have a longer lifespan than wood. It is suitable for frontcountry use. The FRP pony truss bridge design has steadily improved over the last decade. This bridge design is gaining popularity in urban trail programs where a lightweight and easy to assemble trail bridge fits with the capabilities of volunteer trail crews. (See Photo 16.13.)

16.2.10.2.Attributes

One of the most appealing attributes of this bridge design is that it can be purchased as a complete package. The bridge is pre-manufactured and can be shipped fully assembled, partially assembled, or in light packable units. This design is easy to assemble and requires minimal carpentry or construction skills, making it desirable to trail programs with an unskilled labor force. Similar to the FRP I beam bridge, the FRP pony truss bridge is a good design for coastal or chronically wet environments. If used in a coastal environment, the standard fasteners supplied with this bridge will need to be replaced with stainless steel fasteners. (See Photo 16.13.)



Photo 16.13 - FRP Pony Truss Bridge

16.2.10.3.Limitations

An FRP pony truss bridge needs to be purchased through a manufacturer with a licensed engineer. The engineer will design the bridge to meet the required load capacity and site conditions. Note that most FRP pony truss designs do not support 100 pounds per square foot of live load. This bridge is good for spans of 12 to 90 feet. Depending on how the bridge is ordered, it can be carried by hand or transported by stock, wheeled trail cart, rigging, or helicopter. It also needs to be kept out of direct sunlight because it will degrade when exposed to ultra violet light. Although it comes in a variety of colors, the truss assembly can be visually unattractive. Choosing a setting that does not offer a full view of the bridge will help mitigate this issue. This style of bridge may not be suitable for trail programs that have a rustic architectural style. The cost of constructing this style of bridge on average is comparable to steel I beam and FRP I beam bridges and less expensive than steel truss and suspension bridges.

16.2.11. Suspension Bridge

16.2.11.1.Applications

Although a metal truss bridge can be purchased with a span over 200 feet long, this design is limited to use in sites with heavy equipment access. Generally, when the bridge span exceeds 120 feet, a suspension bridge becomes one of the most viable options, especially when the site is remote and not near a trailhead or road access. This bridge design is suitable for both front and backcountry uses. A suspension bridge is supported by two main catenary steel wire ropes. These ropes are supported by towers on each end of the bridge and

are anchored into bedrock or concrete that counteracts the tension or load on the wire rope. The deck is hung from suspender cables or steel rods. The deck is usually sawn timber planks but can be comprised of metal as well. Long span suspension bridges are usually designed with a stiffening truss, which supports and stiffens the decking. (See Photo 16.14.)



Photo 16.14 - Suspension Bridge

16.2.11.2.Attributes

When a long trail bridge is needed in a remote setting, the suspension bridge often becomes the only viable option. It can be designed to support either foot or stock traffic. Depending on the design, this bridge can be fabricated in relatively small components that can be transported into remote sites.

16.2.11.3.Limitations

Today's suspension bridge requires stamped plans from a licensed engineer. This complex structure is subjected to substantial forces. Dead, snow, live, seismic, and wind shear loads must all be accounted. In addition, the oscillation that can be generated by traffic moving across the bridge must be accounted. Local site conditions require close evaluation when designing for all of these factors. Constructing this bridge requires a skilled workforce. Agencies that do not have qualified engineers or a skilled trail crew should consider contracting out the design and construction of a suspension bridge.

A suspension bridge is good for long to very long spans (80 to 400 feet). Generally spans over 120 feet will require some type of stiffening truss design in addition to the catenary wire ropes. Depending on how the bridge was designed,

the components can be carried by hand or transported by stock, wheeled trail cart, rigging, or helicopter. Depending on the design, the towers and the wire ropes from which the bridge suspends can be visually obtrusive. Selecting the proper setting for this type of bridge can help mitigate this issue. The major components of the bridge, such as the towers, concrete anchors, wire ropes, rods, brackets, and turnbuckles, should last for many decades if galvanized. The wooden components will last from 15 to 30 years depending on the species of lumber and the local climate. The cost of constructing this style of bridge on average is more expensive than most bridge designs except steel truss bridges.

16.2.12. Pipe Bridge

16.2.12.1.Applications

A pipe bridge consists of stringers, braces, decking, pipe brackets, pipe stanchions, vinyl coated wire rope, and pipe anchors. A pipe bridge serves as a temporary watercourse crossing where public access is required for only a short period of time. It is commonly used during the summer months. Often it is used to cross a river that has a broad and braided channel that becomes shallow and narrow in the summer. A pipe bridge is primarily a frontcountry application. It also can serve as a temporary crossing when a permanent bridge fails and is in the process of being replaced. A trail crew may install a pipe bridge to provide safe access at a bridge construction site. This application also reduces bank degradation and stream channel impacts. (See Photo 16.15.)

16.2.12.2.Attributes

A pipe bridge is constructed in 8 foot sections that are easy to fabricate. The sections are designed to couple together so a bridge of any length can be assembled. The materials (except the pipe brackets) can be purchased at most lumber yards. The bridge sections can be constructed at the shop and assembled (or disassembled) quickly by trail crews with minimal skills. (See Appendix I for additional information on pipe bridge construction plans.) The length of the pipe stanchions can be adjusted to compensate for varying water depths and to provide additional freeboard where small water crafts may pass under the bridge. Bridge sections can be stored near the crossing site (above high water flow) to minimize annual transportation requirements.

16.2.12.3.Limitations

This structure is limited to pedestrian use. It can be constructed in any length from 8 feet to several hundreds of feet. All of the bridge components can be transported via trail cart or hand packing. Depending on the species of lumber and the local climate, the bridge sections can have a relatively short life span. Even redwood, cedar, or pressure treated lumber will not last more than 15 years in a cool wet climate. This bridge is not intended for year-round use. It should only be used during low flow conditions. During storm events, a pipe bridge can

restrict the flow of water and debris, creating a dam that could result in substantial resource damage and the loss of the bridge. The cost of constructing this style of bridge on average is cheaper than all other bridge designs.



Photo 16.15 - Pipe Bridge

16.2.13. Architectural and Historical Considerations

Another important consideration in selecting the bridge design is the predominant architectural style used by the agency managing the trail system. State and national parks and forest agencies often have a particular style of architecture that is applied uniformly throughout their management areas. The style is often based on historical practices or the need to comply with a historical setting. The bridge design may need to correspond with the surrounding architecture, which often can be accomplished simply by using the appropriate materials and finishing techniques on the bridge's superstructure.

16.3. **Selecting an Abutment Design**

Once the bridge site and design are selected, determine the abutment type. Abutments are the foundation upon which the bridge sills rest. The type of abutment used will be based on the site conditions and the selected bridge design. Among the site conditions to be considered are the strength and stability of native soil; surface and sub-surface drainage conditions; the elevation difference between the right and left banks; the amount of free board required to keep the bridge above future flood events; the availability and suitability of local building materials; the steepness of the hillslope; and the elevations and configurations of the approaching trail alignments. The bridge design will influence the abutment loading requirement, surface contact (displacement), finished elevation, building materials, architectural design, and number of required anchors.

When constructing a trail bridge a variety of abutment designs can be employed. The applications, attributes, and limitations of the most common abutment designs are discussed below.

16.3.1. Earthen/Rock Abutment

16.3.1.1. Applications

The simplest type of abutment, the earthen/rock abutment, is a flat, level spot excavated into the hillside above the watercourse crossing where the end of the bridge will rest. (See Photo 16.16.) The ideal parent material for this type of abutment is exposed bedrock because it provides the strongest and most durable foundation. However, it is more likely that the parent material will consist of a combination of rock and soil or just mineral soil.



Photo 16.16 - Earthen Abutment

16.3.1.2. Attributes

An earthen/rock abutment is the simplest and most economical foundation for a trail bridge. It requires virtually no materials and the least amount of construction knowledge and skills to build. Standard trail construction tools and skill sets are usually all that is required to excavate this abutment. If mechanized equipment, such as a trail dozer, mini excavator, jack hammer, or toter, can be used, the excavation of this abutment can be greatly expedited. If the bridge site was properly chosen and the soil and substrate are stable, an earthen abutment should last many decades with little or no maintenance.

16.3.1.3. Limitations

The most limiting factor in selecting this type of abutment design is the stability and load bearing strength of the parent soil. Since a bridge is usually constructed in an inner gorge, it is not uncommon to encounter soil that is saturated, poorly drained, or comprised of soil particles lacking the requisite strength and cohesion. Locating the bridge properly will minimize some of these problems but it is not always possible to locate two facing abutment sites with the necessary parent soil. In addition, it may not be possible to locate a site where the right and left banks have the same or nearly the same elevation.

Another limitation of this design is that placing the bridge at ground level may not provide sufficient free board during peak storm events. A site with a steep hillslope may require extensive excavation to carve out the appropriately sized abutment and establish a stable slope above the abutment. Therefore, it is not uncommon to have one abutment of an earthen/rock design and the other of a different design to overcome soil strength and stability, drainage, hillslope gradient, or elevation problems.

16.3.2. Soil/Rock Retention Abutments

If the parent soil, hillslope gradient, or bank elevation are insufficient for a simple earthen/rock abutment, construct some type of soil/rock retention abutment to achieve the structural stability, drainage, reduced construction footprint, or elevation required. This structure can be designed using a variety of native and non-native materials. Typically, to establish a solid base on which to build the abutment, native soil must be excavated after all vegetation, organics, and topsoil have been removed. The footing or foundation for the structure must be comprised of firm and consolidated mineral soil, aggregate, or rocks. Even the most sophisticated and well-built abutment will fail if the ground it is constructed upon is subject to slumping, sliding, or raveling. A soil/rock retention abutment is filled with well-drained aggregate soil or rock cobbles to promote drainage and reduce pore pressure. Once filled, the backfill of the retaining structure becomes an earthen/rock abutment for the bridge's mudsills to rest upon. Thus, the backfill requires very careful compaction because differential settling could compromise the structure resting on it.

It is also important that the mudsill fully rests upon the abutment to prevent uneven loading and settling.

16.3.3. Interlocking Wooden/Plastic Cribbed Abutment

16.3.3.1. Applications

An interlocking wooden or plastic cribbed abutment can be used to stabilize native soil, minimize excavation into the hillslope, or increase the height of the bridge. It can be constructed from dimensional lumber, split materials, logs, or structural grade plastic wood. (See Photos 16.17 and 16.18.) The use of this retaining structure is thoroughly discussed in Chapter 13, *Retaining Structures*.

16.3.3.2. Attributes

An interlocking wooden/plastic cribbed abutment is very effective at containing and retaining fill. It can be used for almost any type of bridge design and has the capacity to retain moderate amounts of fill. If on-site native materials are used, the structure may be less expensive and will blend in well with the environment. Non-native materials, such as structural grade recycled plastic wood, are not subject to rot and have a long life span.



Photo 16.17 - Wooden Cribbed Abutment



Photo 16.18 - Plastic Wood Cribbed Abutment

16.3.4. Multi-Tier Rock Abutment

16.3.4.1. Applications

A multi-tier rock abutment also can be used to stabilize native soil, minimize excavation into the hillslope, or increase the height of the bridge. Usually it is constructed with on-site native rock; however, if the site is relatively close to the trailhead, suitable rocks can be imported. This structure is constructed in tiers and uses gravity and friction (dry stone masonry) or gravity, friction, and mortar (wet masonry) to unitize the rocks. (See Photos 16.19 and 16.20.) The use of this retaining structure is thoroughly discussed in Chapter 13, *Retaining Structures*.



Photo 16.19 - Dry Stone Multi-Tier Rock Abutment



Photo 16.20 - Multi-Tier Mortared Rock Abutment

16.3.4.2. Attributes

This structure is very effective at retaining and containing moderate amounts of fill. If native materials generated during excavation or gathered on-site are used, this structure can be comparatively inexpensive and blend well with the environment. When properly constructed, a rock retaining structure will have the longest life span of any building material. A dry stack rock retaining wall can last hundreds of years. Many rock structures built by ancient cultures over a thousand years ago are still functional today. A wet masonry wall has a shorter life span because it tends to deteriorate once the mortar begins to fail. Nevertheless, the life span of a wet masonry wall is significantly longer than other styles of retaining structure.

16.3.4.3. Limitations

Constructing this retaining structure requires trail workers that are skilled in rock masonry. This structure is labor intensive and the logistics of transporting, moving, and placing rock can be difficult, time consuming, and hazardous. Finding suitable rock within close proximity to the worksite may be a limiting factor. If rock is imported from a commercial quarry, they may not allow the trail crew access to select and sort the desired rock. It may also be difficult to find rock with the same color and texture as the on-site native material. The distance of travel, access to water (for wet masonry), and transportation logistics from the trailhead to the worksite may make importing rock cost prohibitive.

16.3.5. Concrete Abutments

16.3.5.1. Applications

Concrete is frequently used to construct trail bridge abutments especially at or near a trailhead. A concrete abutment can be constructed and integrated onto an existing bedrock formation or can be constructed as a free standing structure. It can be fabricated to include a beam seat for the stringers to rest upon and a soil dam to separate the bridge stringer from contact with surrounding soil. (See Photo 16.21.) Sometimes an elastomeric pad is placed between the metal bridge stringer and the concrete or metal bridge bracket to cushion the contact area. This pad also compensates for the different expansion and contraction rates associated with concrete, metal, and wooden components. The use of concrete as a building material in trails is discussed in Chapter 20, *Materials*.

16.3.5.2. Attributes

When properly designed and constructed, a concrete abutment can provide a uniformly durable and long lasting foundation for a trail bridge. It will outlast wooden bridge components and can be reused after the bridge's stringers and superstructure lose their structural integrity and are in need of replacement. Concrete is fire resistant and, if treated with an air entrainment additive, is resistant to spalling in cold weather conditions.

16.3.5.3. Limitations

The use of concrete in constructing a bridge abutment is usually limited by the accessibility of the worksite and the distance from the nearest trailhead. Generally, only small concrete pours can be attempted in remote locations due to the problems of transporting materials, mixing, water availability, and curing time. Designing, laying out, forming, and pouring a concrete abutment require engineering and advanced carpentry skills, which are not available in most trail programs. Concrete can be an obtrusive building material and may not blend in well in some locations. Facing the concrete abutment with a mortared rock façade can mitigate this issue. Stamping the concrete with various patterns and/or coloring the concrete may also help blend the bridge abutments into the environment in frontcountry locations.



Photo 16.21 - Concrete Abutment

16.3.6. Trestle Abutments

16.3.6.1. Applications

A trestle is a structure consisting of a supporting mudsill, center support column, outside support columns, trestle sill, and cross bracing. In trail design, it can be used as an abutment to support the ends of a bridge or as a mid-span support. When used to support the end of a bridge, it acts similarly to the bridge abutment designs previously discussed. When used as a mid-span support, a trestle can support a single linear bridge span by being placed at appropriate intervals underneath the stringer. In this application, the trestle increases the structural capacity of the stringer by reducing its free span. A trestle can also be used to support two stringers joined to complete one bridge span. In this application, the stringers in the bridge span join on top of the trestle. This application also allows for shorter and smaller stringers to be used. In some locations, a single span bridge is inadequate to meet the requirements of the site. The span may be too great for the preferred style of bridge, the abutments may be grossly out of level, or a single straight bridge structure may be aesthetically unacceptable. In these situations, a trestle may be a good alternative.

The logistics of transporting and placing long, single span bridge stringers are sometimes difficult. A number of variables, such as distance to the bridge site and the terrain over which the stringers have to be transported, may determine the maximum length stringer that can be practically transported to a given site. In extremely remote sites, transporting stringers by hand packing, wheeled carts, stock, or rigging techniques might be prohibitively time consuming. Transporting them via a helicopter may be prohibited by statute or policy, or simply because it is too costly.

A trestle can be constructed using rot-resistant wood, such as redwood, Alaskan yellow cedar, or pressure treated Douglas fir. It also can be constructed using all-weather steel. Depending on the weight or span of the bridge, a single or double trestle design may be used. (See Photos 16.22 and 16.23.)

16.3.6.2. Attributes

The trail approach, site conditions, or soil stability may require the use of abutments that are not level to each other. A trestle may be used on the lower abutment to provide a level crossing and eliminate the need to construct a massive cribbed or concrete abutment. From the trestle end of the bridge, a cutout stringer stairway could be constructed to meet the trail at the lower abutment grade; a retaining wall could be constructed to support an earthen ramp from the end of the bridge to the approaching trail; or an additional approach bridge could run off the trestle to meet the approaching trail on the hillslope.

Sometimes a bridge site may have a small island or bedrock outcrop in the channel that is above the potential flood water elevation and stable enough that it can be utilized for an abutment location. Constructing a trestle upon this outcrop allows for the use of two short bridge spans and avoids having to construct one long span.

An inner gorge sometimes has a terrace adjacent to the active channel that is a remnant from when the water was flowing at a higher elevation, before it eroded down to its current elevation. Such a terrace is often located far above 100 year flood water elevation. Rather than constructing a single span bridge across this terrace and onto the adjacent hillslope, a trestle can be constructed on the terrace to allow the use of two short bridge spans instead of one long span.

The use of a trestle as a mid-span bridge support also allows the designer to alter the line or appearance of the bridge. A long span bridge often clashes with the surrounding setting because it is a prominent, linear feature in an environment that is non-linear. If the designer has two bridge spans meeting on a trestle to form an obtuse angle, then the line of the bridge will be broken and the structure will blend into the setting better and be less obtrusive. (See Photo 16.24.)



Photo 16.22 - Double Trestle



Photo 16.23 - Single Trestle



Photo 16.24 - Using Trestle to Alter Bridge Alignment

16.3.6.3. Limitations

Sometimes a trestle is placed within the flood plain of a creek. In this case, the trestle abutment must not be located in an area where it can become eroded and undermined by the water, catch floating debris, or adversely affect or alter the stream's hydrology or morphology. Thus, if a trestle abutment is constructed in an active flood plain, it should be placed on a secondary terrace that only receives flows during a 100-year or greater flood event. Its placement should be outside of the turbulent flow of the creek where only slack water exists. The depth of the foundation for the trestle in this case should begin a minimum of 2 feet below the thalweg of the active stream channel to protect the trestle from being undermined during the most severe flood events. A qualified hydrologist or engineering geologist should be consulted prior to designing a trestle for use in an active flood plain.

When a trestle is used as an abutment for one end of the bridge it cannot be attached to the approaching trail without the use of another structure such as a step carriage, bridge, or earthen ramp supported by retaining walls.

16.3.7. Abutment Sills

An abutment sill is the structural member on which the bridge stringer is set and to which the stringer is fastened. The sill is usually constructed of wood, plastic wood, or concrete. The abutment sill anchors the bridge stringer to the abutment and provides a barrier and air gap between the stringer and the surrounding soil and vegetation. (See Photo 16.25.)



Photo 16.25 - Abutment Sills

16.3.7.1. Types of Abutment Sills

Wooden and plastic wood abutment sills are commonly called mudsills or simply sills. A mudsill can be used with an abutment of native earth, interlocking wood/plastic wood, interlocking log, or multi-tier rock. Unlike concrete sills, wooden and plastic wood mudsills are not constructed on site but are purchased and then installed on the abutments. The mudsill rests upon a level abutment and is anchored by driving rebar through the mudsill and into the abutment soil or fill material. A beam seat bracket is attached to the mudsill with lag screws. The beam seat bracket anchors the bridge stringer to the mudsill when the stringer is bolted to the bracket.

If a wooden mudsill is used, it should be comprised of rot-resistant wood such as con heart redwood, Alaskan yellow cedar, or pressure treated Douglas fir. A wooden mudsill comprised of these materials should have a life expectancy that exceeds a log, milled wood, or glulam stringer. It is recommended that wooden mudsills be of large dimensions (14 x 14 inches) to provide the most load bearing surface contact, longevity, stability, and separation from surrounding soil and vegetation.

Plastic wood is a relatively new material for mudsills. Although recycled plastic wood has been around for some time, only recently has it been offered in dimensions suitable for a mudsill. Plastic wood is now offered in 12- x 12-inch and 12- x 15-inch dimensions. This material should last many times longer than a wooden mudsill, making it a good match for long lasting bridge stringers such as all-weather steel, aluminum, or fiber reinforced plastic.

Concrete can also be used to form and pour a sill on top of compacted native soil, fill material (used in retaining abutment structures), or bedrock. A concrete sill is formed and poured with anchor bolts that are used to attach beam seat brackets to the sill. These brackets are used to secure the bridge stringer to the concrete sill in the same manner as the mudsill beam seat brackets.

16.3.7.2. Sizing an Abutment Sill

Regardless of the style of sill selected, it must be adequately sized to support the weight of the bridge and all its components (dead load), as well as the weight of the bridge users (live load). The typical live load for trail bridges in the California state park system is 100 pounds per square foot. The sill for a bridge at a high elevation may also need to be designed to support the additional dead weight associated with snow. The size refers to the total surface area of the sill that comes into contact with the abutment. As the load bearing capacity of the native ground decreases, the sill's surface area contact must increase. The larger and heavier the bridge structure, the more surface area contact is required of the sill. Refer to the pre-engineered sill size chart for typical wooden trail bridges for further information. (Figure 16.7.)

Before an abutment site can be properly laid out, cleared, and excavated, determine how much area is needed for the sill. Otherwise, it may be too small or too big for the required sill, which can result in inefficiencies, over excavation, and increased resource impacts.

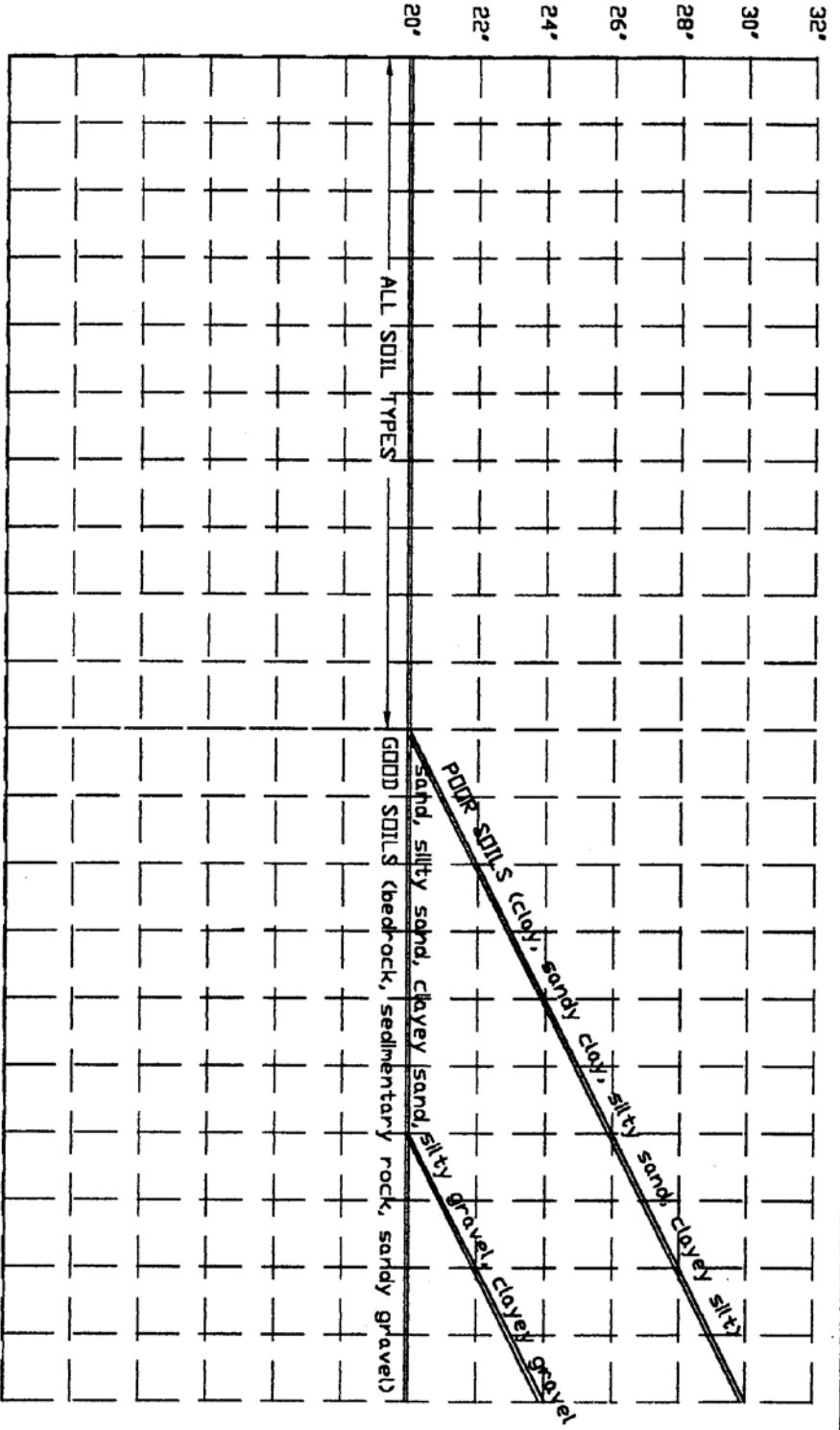
Using the sill size chart in Figure 16.7 and the concrete abutment detail for a typical wooden trail bridge in Figure 16.8, a 30-foot long milled stringer wooden bridge constructed on stable soil (bedrock, sedimentary rock, or gravel) requires a sill surface of 20 inches wide and 84 inches long (approximately 12 square feet).

The sill must be at least as wide as the designed width of the bridge stringers (outside to outside measurement). The standard bridge width in this handbook is 5 feet between railings, which is also the outside to outside width of the bridge stringers. Given these requirements, two 5-foot long, 14- x14-inch sills could be used and there would still be enough surface area to support the weight of one end of the bridge. However, a sill can also serve as an outrigger that stabilizes the bridge and keeps it from being tipped or tilted from sideways forces. A wooden or plastic wood mudsill may also be used to support and attach a post and post braces. This design is usually applied to log or milled wooden stringers, up to 30 feet in length, that lack the height to fully support the posts that are bolted to the stringers. (See Photo 16.26.) Glulam bridge stringers, up to 16 inches in height may also require a post sill to provide additional support for the posts. If it is necessary to use post braces for additional support, one 14- x 14-inch mudsill, 10 feet long should be prescribed instead of two 5-foot long mudsills.

EXAMPLE 1. BRIDGE SPAN IS 33' (HALF SPAN IS 33'/2=16.5'). SOIL TYPE IS SANDY CLAY. ABUTMENT WIDTH FROM GRAPH IS 26.5', USE 27'.

EXAMPLE 2. BRIDGE SPAN IS 20' (HALF SPAN IS 20'/2=10'). SOIL TYPE IS ROCK. ABUTMENT WIDTH FROM GRAPH IS 20'.

ABUTMENT FOOTING WIDTH (INCHES)



NOTES:
 IF WOOD IS SUBSTITUTED FOR THE CONCRETE ABUTMENT USE F.N.D. GRADE TREATED WOOD. THE WOOD SHOULD BE TREATED THE FULL LENGTH. DO NOT CUT WOOD ON SITE AND HAND TREAT.
 IF SOIL TYPE IS QUESTIONABLE USE POOR SOILS OR HAVE THE SOIL TESTED BY A SOILS LAB.

USE THIS GRAPH TO FIND THE WIDTH OF THE ABUTMENT. SEE SHEET FOR TYPICAL ABUTMENT DETAIL.

Figure 16.7 - Abutment Footing Sizing Chart

CALIFORNIA PARKS AND RECREATION TYPICAL WOOD TRAIL BRIDGE ABUTMENT WIDTH VS. SPAN GRAPH	REVISIONS _____	DATE _____	DESIGNED & DRAWN BY _____
	DEPARTMENT OF PARKS AND RECREATION	APPROVED _____	DATE _____

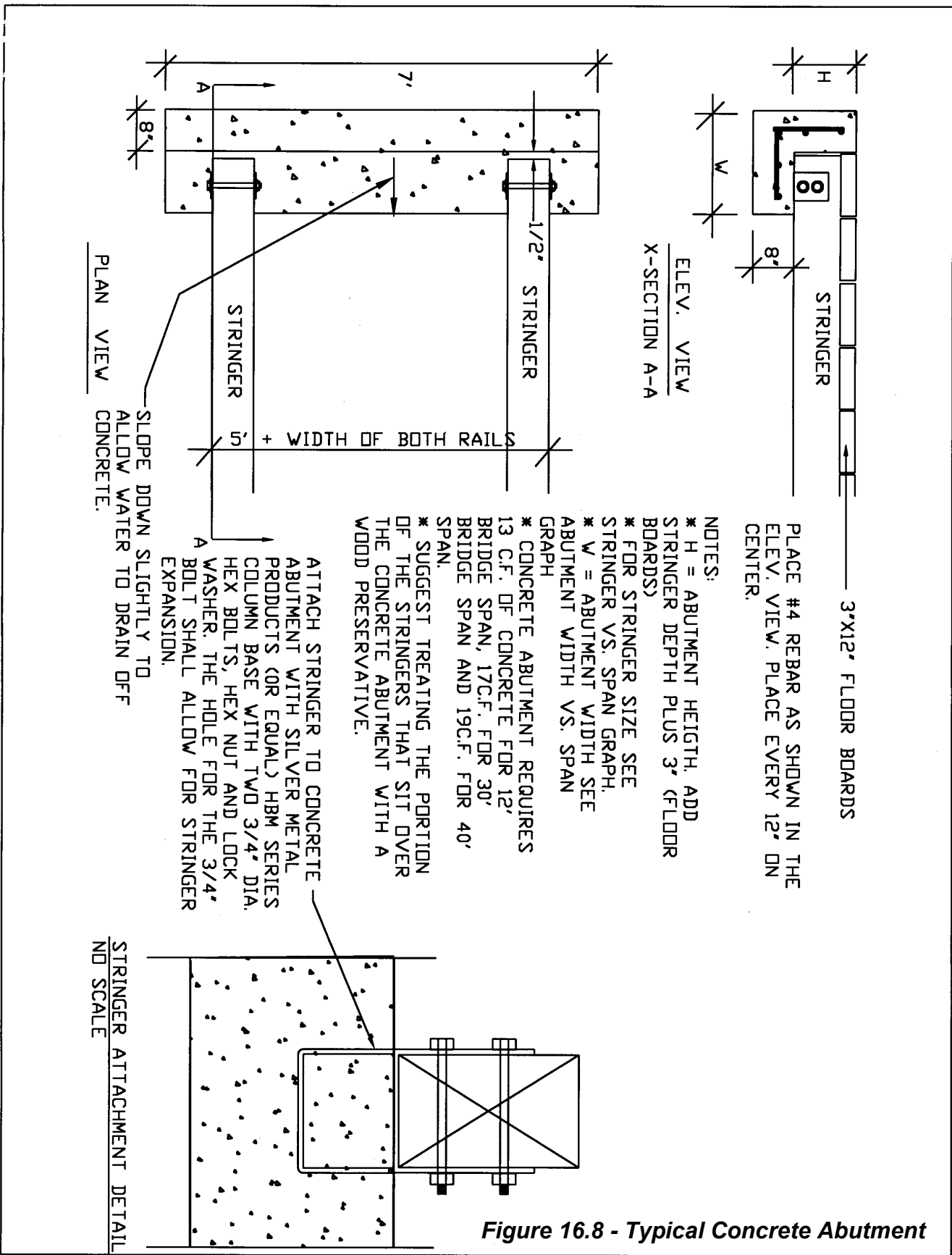


Figure 16.8 - Typical Concrete Abutment

CALIFORNIA PARKS AND RECREATION TYPICAL WOOD TRAIL BRIDGE CONCRETE ABUTMENT DETAIL	RESOURCES AGENCY OF CALIFORNIA DEPARTMENT OF PARKS AND RECREATION	REVISIONS _____ _____ _____	DATE _____	DESIGNED G STEPHENS DRAWN G STEPHENS CHECKED SERRS
	APPROVED _____ DATE _____			



Photo 16.26 - Use of Mudsills, Post Sills, and Braces

16.3.7.3. Length of a Mudsill

The required length of the mudsill must be calculated when the stringers have insufficient height to secure the posts by bolting. The calculation is as follows:

$$L = W + 2(H) + 3(P + B)$$

L = Mudsill length

W = Width of bridge (outside to outside of stringers)

H = Height of stringers

P = Thickness of post

B = Length of the end of the post brace cut at 45 degree angle

For example, a 30-foot milled stringer bridge would require two 10- x 16-inch Douglas fir stringers. The bridge design requires a 5-foot width between the railings and 4- x 6-inch railings and posts. Based on these specifications, the minimum mudsill length can be calculated as follows:

$$L = (60 \text{ in.}) + 2(16 \text{ in.}) + 3 (3.5 \text{ in.} + 7.5 \text{ in.}) = 60 + 32 + 33 = 125 \text{ in. (10 ft. 5 in.)}$$

In the example above, the 14- x 14-inch mudsill should be 10 feet 5 inches long to provide the required length.

16.4. Initial Best Management Practices

Laying out the abutments requires crossing the watercourse, often numerous times, which can result in the destruction of riparian vegetation, bank erosion, and stream bed disturbance. The best way to eliminate these problems is to establish a temporary crossing that can be used for the entire project. Although the layout activity represents a minor issue in terms of disturbance, it is just the precursor to the destruction that can occur when personnel and materials are moved across the watercourse once construction begins.

If high anchors are available, installing a wire rope skyline directly over the abutments will provide a means of transporting both personnel and materials across the watercourse. A temporary bridge, such as a pipe bridge, will also facilitate the movement of personnel and materials across the watercourse. (See Photo 16.27.) In a small watercourse, scaffolding and planking can be assembled to facilitate a temporary crossing, for example. The goal is to keep personnel away from the riparian vegetation, streambanks, and streambed.

In addition, appropriate erosion control measures must be installed between the abutment layout area and the watercourse to prevent the migration of disturbed soil into the watercourse. A well-planned and executed bridge construction project will avoid unnecessary resource damage and add credibility to the environmental review and permitting processes. See Chapter 27, *Trail Removal and Site Restoration*, and Appendix C, *Best Practices*, for further detail on these measures.



Photo 16.27 - Pipe Bridge Temporary Crossing

16.5. Abutment Layout

Having selected the best site for the bridge, identified the required bridge span, selected the appropriate bridge and abutment designs, and identified the size of the abutments, the next step is to layout the abutments. Since the abutments serve as the foundation for the bridge, they should be constructed square and level to each other. The stringer tables in this handbook and the pre-engineered bridge stringers purchased from manufacturers are sized for level bridges. Constructing a bridge “out of level” means more of the total weight (“dead load” and “live load”) is born by one end or side of the bridge. The force of gravity will unequally distribute the weight to the downhill end or side of the bridge. Sometimes a bridge structure is intentionally designed and constructed with a moderate linear grade (end to end). Such a structure must be specifically engineered to compensate for uneven loading. Also, a bridge deck with even a moderate linear grade can be difficult if not hazardous to traverse in wet or icy conditions. A level bridge is much easier to traverse especially for trail users with a mobility impairment.

16.5.1. Establishing a Center Line and Clearing

Prior to establishing the elevations and squaring the abutments, the direction or orientation of the bridge, as well as its starting and end points, must be established. Similar to the layout out of a boardwalk in Chapter 15, *Timber Planking, Puncheon, and Boardwalk Structures*, the trail Work Log and flag line are used to locate the starting and ending points of the bridge and its general alignment on the ground. Lay a cloth or steel tape measure on the ground along the center line of the intended structure so that it extends a minimum of 10 to 15 feet beyond the footprint (including the abutments) on both ends. Drive two 5/8-inch x 5-foot metal form stakes into the ground at these two locations. Longer stakes may be required if the locations have a substantial elevation difference. Next, tie builder’s string to one of the stakes, stretch it to the other stake, and tie it off so that the string is taut. Note, some vegetation may need to be removed if it interferes with the string. Metal form stakes have holes running through the center of them. The string line is run through the hole, wrapped around the stake three or four times, and tied off with two half-hitches. A 12-inch pipe wrench can be used to turn the stake if the holes don’t line up with the direction of the bridge. The stakes and builder’s string should be high enough off of the ground so that the string freely clears the ground along its entire length. (Figure 16.9.)

Locate the starting point of the bridge along this string line and drive a start-of-bridge form stake into the ground next to the string line. Then use a cloth or metal tape to measure along the center string line to the end point of the bridge on the opposite bank. This measurement should equal the total length of the bridge stringers. Drive in an end-of-bridge form stake next to the string line at this location. The distance between the two stakes is the total length of the bridge stringers. The thickness of the soil dam will be added to this length at a later time.

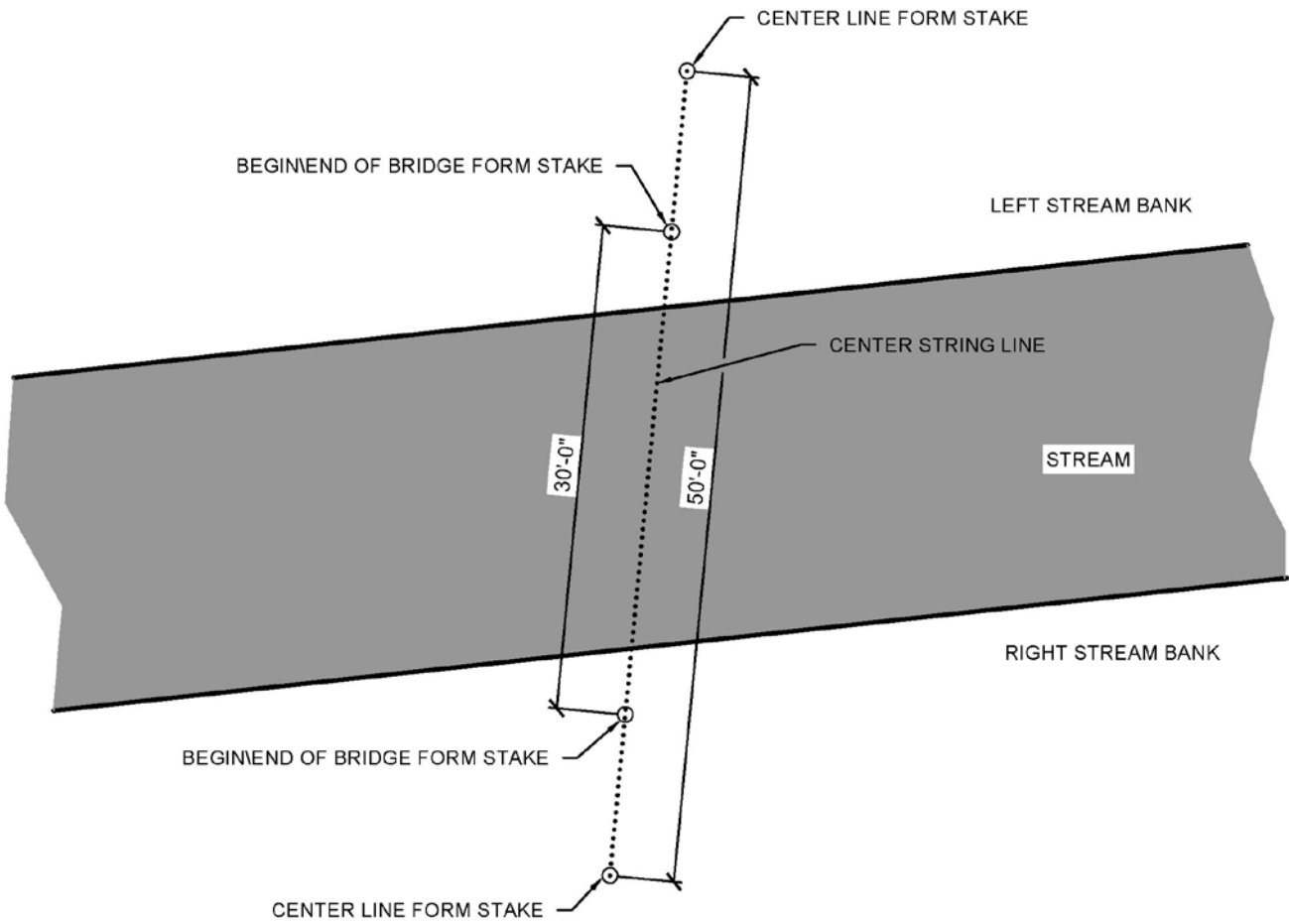


Figure 16.9 - Bridge Layout Alignment and Begin/End Points



BRIDGE LAYOUT ALIGNMENT AND BEGIN/END POINTS

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Using the square footage requirements of the pre-determined abutment style, set pin flags in the ground or tie rolled flagging on the vegetation in the front and back of the begin/end-of-bridge form stakes and on either side of the string line to mark the perimeter of the abutments. Be sure to add another 2 to 3 feet of clearance on the sides and ends of this area to provide room for the future installation of batter boards. This process establishes the approximate footprint of the bridge. (Figure 16.10.) Untie the centerline string and remove the two form stakes marking the ends of the bridge. Then remove any vegetation that will interfere with the layout of the bridge. Since the bridge site is likely to be within a riparian plant community, only remove the vegetation within the flagged area. If the abutment will be located on bedrock, remove any vegetation and loose rocks. Follow the brushing guidelines established in Chapter 11, *Principles of Trail Construction*, for the removal and stashing of vegetation.

After the vegetation is cleared, remove the organics and excavate the abutment area down to mineral soil. When working within the influence of a watercourse, all organics and mineral soil must be exported to a location where they cannot be washed into the watercourse. See Chapter 27, *Trail Removal and Site Restoration*, for further detail on these measures.

16.5.2. Determining the Abutment Elevations

After the vegetation and organics have been removed, replace the string line and the begin/end-of-bridge form stakes. Using the footprint of the cleared abutment area, locate which of the four corners of the abutment area is the highest point of ground or has the highest elevation. This determination can be quickly accomplished using a clinometer to sight on the reference point of a coworker. Alternatively, use an Abney hand level or a clinometer on top of a McCloud handle and sight on a tape measure held vertically by another person. Identify the highest corner on both abutment sites.

Once the highest corner for each abutment footprint is established, locate an area outside of these footprints that is equal to or higher than the highest corner. This area should be located where all four corners of both abutment footprints can be clearly seen at the same time. This area is where an auto level is set up. A thorough explanation of setting up and using an auto level and stadia rod is described in Appendix J.

Select one of the abutment areas and use the auto level and stadia rod to sight each corner of the abutment footprint. In addition, sight one location between each corner along the perimeter of the abutment footprint and one location in the center of the abutment footprint for a total of nine locations. Draw a simple plan of the abutment and record the elevations of these locations. (See Figure 16.11.) Repeat this process for the abutment on the opposite bank. Using these elevations, compare the differences in elevation between the two abutments, as well as the ground, within each abutment. Remember, the higher the number on the stadia rod, the lower the ground elevation.

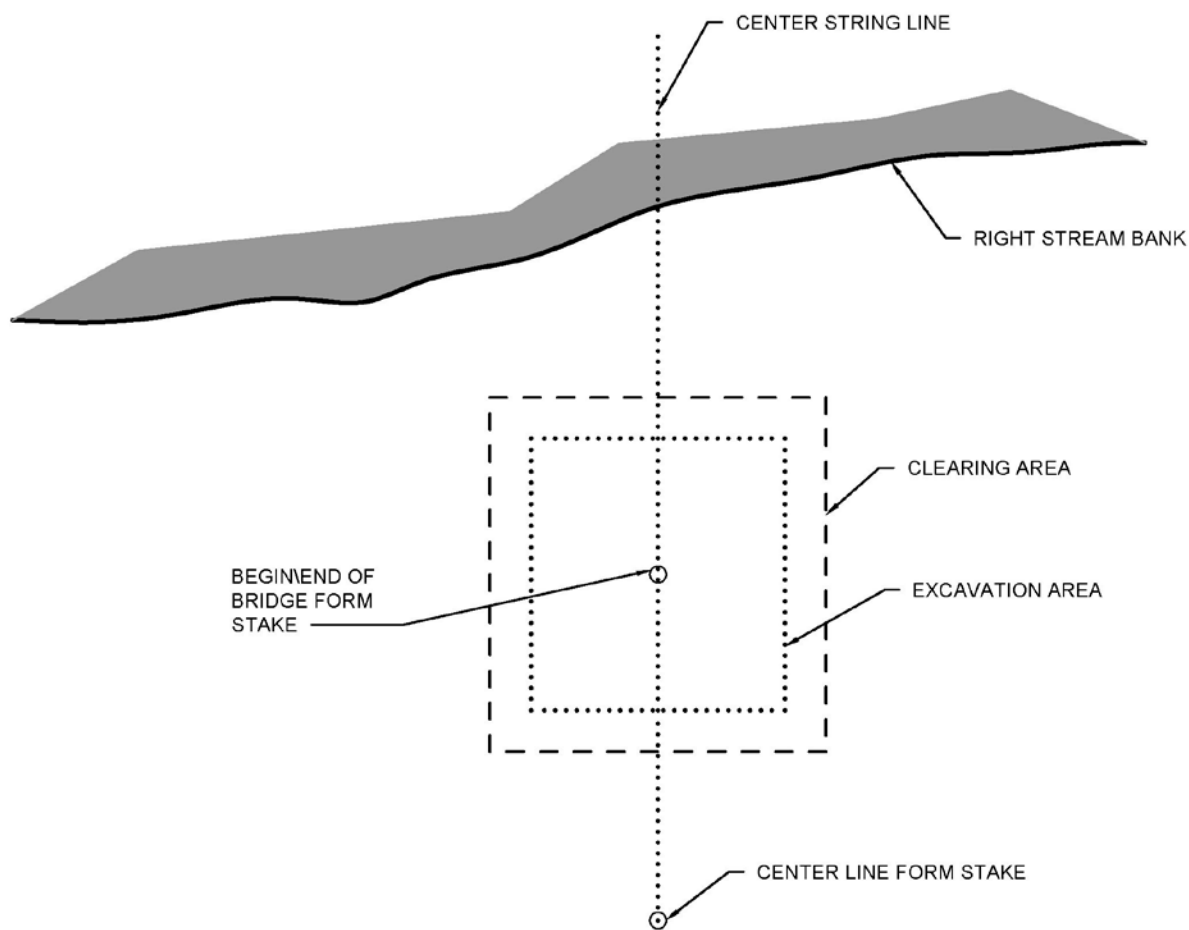


Figure 16.10 - Bridge Layout, Clearing, and Excavation



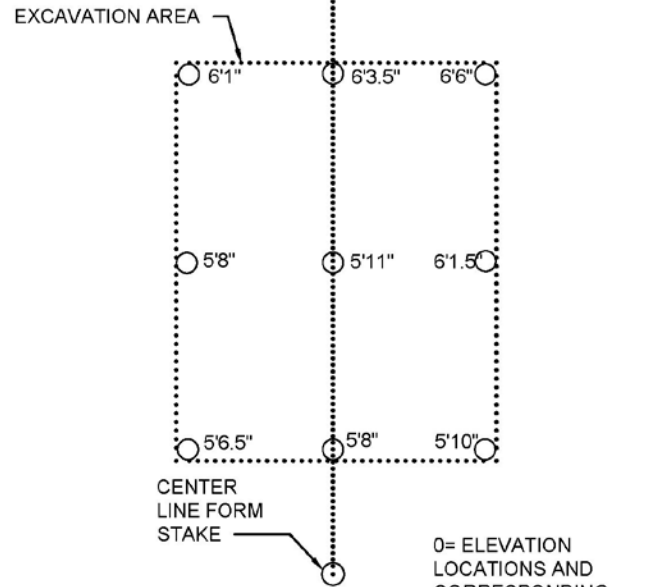
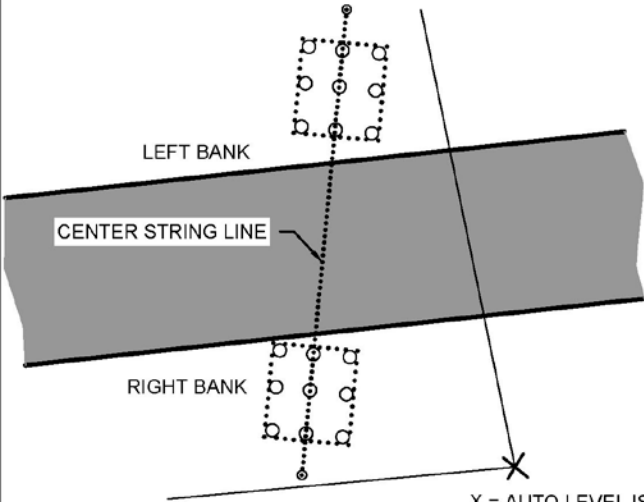
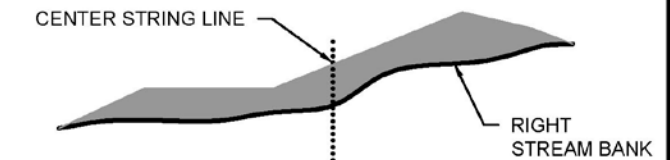
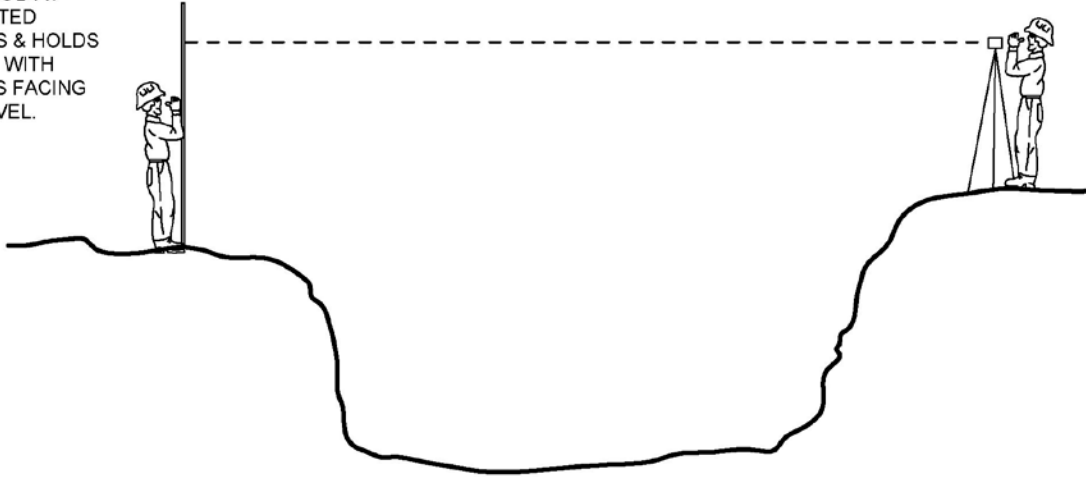
BRIDGE LAYOUT, CLEARING, AND EXCAVATION

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WORKER PLACES STADIA ROD AT DESIGNATED STATIONS & HOLDS IT PLUMB WITH NUMBERS FACING AUTO LEVEL.

WORKER SIGHTS THROUGH AUTO LEVEL AT 0% & READS ELEVATION ON STADIA ROD



O = INITIAL ELEVATION LOCATIONS WHERE STADIA ROD IS PLACED TO OBTAIN GROUND ELEVATION READINGS.

X = AUTO LEVEL IS LOCATED WHERE BOTH ABUTMENT AREAS CAN BE SEEN AND THE GROUND IS HIGHER THAN BOTH ABUTMENT AREAS.

O = ELEVATION LOCATIONS AND CORRESPONDING MEASUREMENTS IN FEET/INCHES. NOTE THE LOWER THE NUMBER THE HIGHER THE GROUND

Figure 16.11 - Determining Abutment Elevations



DETERMINING ABUTMENT ELEVATIONS

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16.5.3. Excavating Earthen Abutments and Abutment Foundations

An earthen abutment with a sill must be excavated to the designed footprint and elevation. For soil/rock retention or concrete abutments, the abutment foundation must be excavated to the designed footprint and elevation to support the abutment structure.

Untie and remove the center string line so it is out of the way. Using the elevations recorded on the plan, excavate each abutment area until it is level. Usually, the footprint must be excavated to the lowest recorded elevation. However, in some instances, a retaining structure may be used in combination with excavation to achieve a level abutment. Also if the abutment areas consist of bedrock, no excavation may be needed as the sill will be formed on top of the bedrock.

During the excavation process, regularly monitor the excavation with the auto level and stadia rod to keep the trail crew informed on their progress and how much material remains to be removed. Elevation readings should be taken throughout the excavation area, not just the initial elevation locations. In addition, a 4-foot carpenter's level attached to a long straight board can be used to evaluate the leveling process and ensure that over-excavation does not occur. Over-excavation will result in having to use earthen fill or aggregate to elevate the low areas. Even when properly compacted, fill areas will lack the load bearing qualities of undisturbed native soil.

Remember, all excavated soil must be exported away from the influence of the watercourse. Normally the approaching trails on each end of the bridge are constructed in a manner that will facilitate the removal of soil by the trail crew. If possible, the exported soil should be used for fill material behind a cribbed retaining wall or similar structure or scattered on a hillslope outside of the influence of the watercourse.

If the two earthen abutments were relatively level to each other and the site conditions warrant it, the earthen abutment with the higher elevation should be excavated to match the elevation of the lower abutment. Again, excavation should be monitored by taking regular elevation readings with an auto or carpenter's level.

During the leveling process, it is essential that the supporting soil is properly compacted. Construction standards often call for compacted fill soil to have a minimum density that is 90% of maximum density, which is specific to each soil. However, it is not likely that this level of compaction could ever be achieved because most trail construction occurs where the use of heavy soil compaction equipment is prohibited.

On most trail projects, plate compactors and jumping jacks are the most effective compaction equipment. Even with ideal conditions, this equipment cannot achieve 90% of maximum compaction. Therefore, it is important that the on-site native soil has good strength and cohesion or be supplemented with high-quality aggregate to

ensure that it is capable of supporting the abutments. Native soil or imported aggregate should be compacted in lifts not exceeding 3 inches to improve compaction and minimize settling. Having near optimum soil moisture is also critical to achieving the desired soil compaction. Time the bridge construction project around good soil moisture conditions or import water to achieve those conditions. Soil that is too dry will not bind well and will have relatively large voids. Soil that is too wet will be soft and have many voids after the soil dries.

Once the earthen abutments or abutment foundations are level, compacted, and prepared for construction, the abutments and sills can be squared.

16.6. Squaring Bridge Abutments and Sills

Squaring bridge abutments and sills can be accomplished with batter boards and string lines, ledger boards, or a combination of the two methods. The method selected often depends on the site conditions, complexity of the abutment and bridge design, and the knowledge and skill level of the trail crew. If the site conditions are such that the abutments are initially somewhat level to each other and the abutment design calls for earthen abutments with wooden or plastic wood mudsills, then the simple abutment layout and squaring methods discussed in Chapter 15, *Timber Planking, Puncheon, and Boardwalk Structures*, are appropriate.

If the site conditions are such that there is a considerable elevation difference between the initial abutment locations, or the abutment design calls for a more complex structure such as concrete abutments with formed beam seats and soil dams, then more precise layout and squaring processes are required. If the bridge abutments are earthen and level to each other, the use of batter boards and string lines works well. If one abutment is significantly lower than the other and must be elevated through the use of a retaining structure or concrete pour, then a combination of batter boards and ledger boards can be used. If both abutments need to be elevated, then the initial layout can use batter boards and string lines but squaring the sills will require the use of ledger boards. Each of these site conditions and methods will be discussed below.

16.6.1. Abutments Not Level to Each Other

If the abutment design calls for excavating the two abutments to the same elevation, the procedure for squaring up the abutments begins with re-tying the center string line. The two center line stakes should still be in their original locations since they were initially installed outside of the clearing and excavation limits of the abutments. Where an earthen or bedrock abutment is used with a simple concrete sill, the center string line should be installed at the designed elevation of the sills. This height is achieved by measuring from the surface of the excavated earthen abutment to the bottom of the center string line once it has been pulled taut. A simpler method of setting this string elevation is to tie the string line to the center line stakes 1 or 2 inches above the designed sill elevation. Then hold a tape measure or stadia rod vertically (“plumb”), resting on the excavated earthen abutment surface and against the string line. (See Figure 16.12.) Carefully drive the center line

stakes down until the designed sill elevation is reached. At this point, the center string line is at the finished height of the sills and should be level from one abutment to the next. Once the center string line has been installed, the stakes marking the ends of the bridge, which were removed prior to clearing and excavating because they would have been within the disturbed area, must be re-installed. Repeat the process for the installation of these stakes as previously described.

16.6.1.1. Installing Side Batter Boards

Side batter boards are used to facilitate the layout and squaring of the bridge abutments and sills. These structures are installed outside of the abutment footprint so they do not interfere with the construction of the abutments. String lines are attached to the batter boards to identify the location of the abutments, sills, beam seats, and soil dams. They also can be used to establish the finished elevations for these components and ensure that all components are square to each other.

From one of the form stakes marking the begin/end of the bridge, measure in both directions 3 1/2 feet along the center string line. Mark the center string line at 3 1/2 feet with a fine tipped felt pen (e.g., Sharpie) or by tying on a small piece of string. Note, if the abutment sills will be further apart than 8 feet, more than 3 1/2 feet will be needed so the batter boards can accommodate the sills. Next, measure at a right angle from the center string line in both directions to a distance that is outside of the abutment or sill construction area but within the area cleared of vegetation. Have another person hold a framing square inside the intersection of the cloth measuring tape just stretched and the center string line previously installed. The body of the square should be laid so it is parallel to the center string line and just resting against it. Adjust the cloth measuring tape being stretched until it is parallel to and just resting against the tongue of the square. Drive in batter board form stakes at the desired locations outside the abutment construction area where it intersects with this squared string line. Record the distance between the center string line and the batter board form stakes just installed.

Repeat this process for the 3 1/2 foot measurement mark on the other side of the end-of-bridge stake. Use the measurements just taken between the center string line and the batter board form stakes to locate how far away from the center string line the next batter board stakes will be set. Ensure that these batter board form stakes are driven firmly into the ground and are plumb. The two sets of batter board form stakes on each side of the center string line should be 7 feet apart and equal distance from the center string line. (See Figure 16.13)

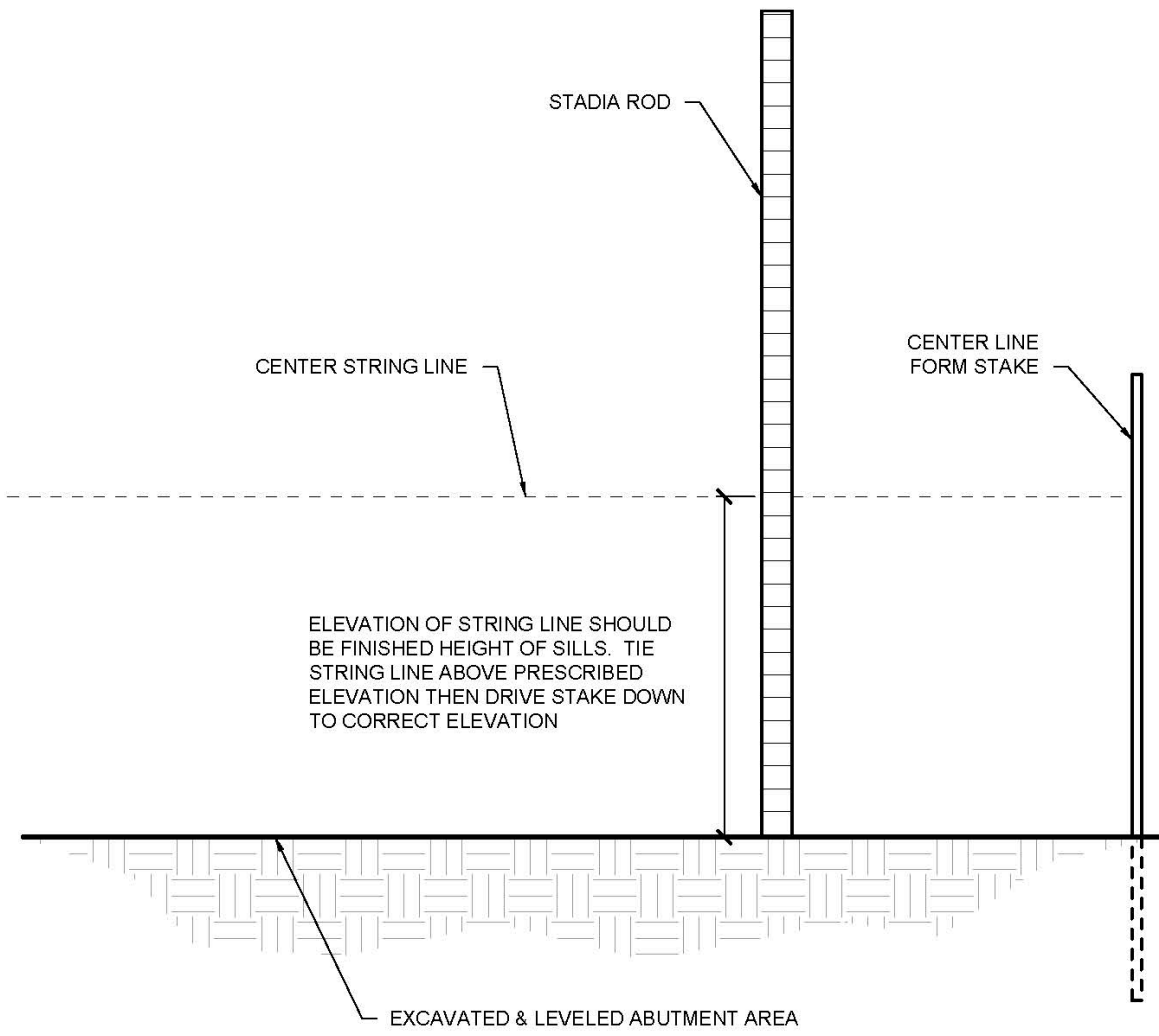


Figure 16.12 - Installing Center String Line at Desired Elevation



INSTALLING CENTER STRING LINE AT DESIRED ELEVATION

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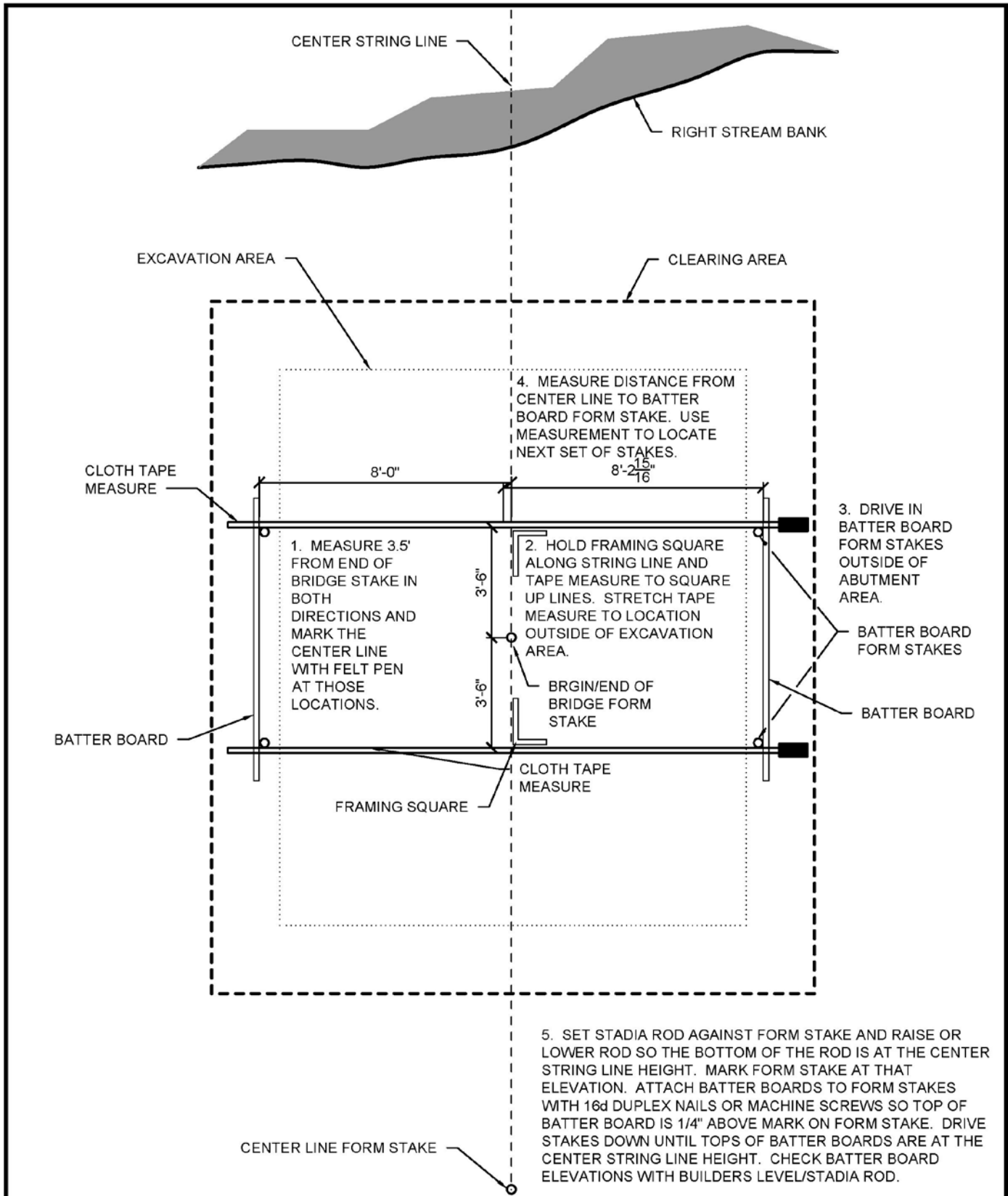


Figure 16.13 - Installing Side Batter Boards



INSTALLING SIDE BATTER BOARDS

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Use a pipe wrench to ensure that the holes in the batter board form stakes are at a right angle to the center string line. Hold the stadia rod plumb against the batter board form stakes, so the bottom of the rod is at the same elevation as the center string line. Mark the batter board form stakes at the elevation. Hold a 1-inch x 6-inch x 8-foot pine, redwood, or Douglas fir batter board against the two batter board form stakes. The batter board should be held so that it is level and the top of the board is approximately 1/4 inch above the center string line elevation. It should also extend beyond each batter board form stake approximately 6 inches.

Use a cordless drill and a 3/16-inch drill bit to drill a pilot hole through the batter board. Use one of the holes in the batter board form stakes as a guide so that the pilot holes and batter board form stake holes line up. Attach the batter board to the batter board form stakes by driving a 16d duplex nail or a 1/8- x 3-inch machine screw through the batter board and batter board form stake hole. Once driven through, bend the duplex nail over against the batter board form stake or tighten the nut on the machine screw to secure the batter board. Use the auto level and stadia rod to check the elevations of the batter board and center string line. Drive the batter board form stakes down until the top of the batter board is the same elevation as the center string line. (See Figure 16.13.) The center string line and the top of the batter boards must be level to each other to accurately square up these lines. Follow this same procedure to install the two batter boards required on the opposite bank abutment.

16.6.1.2. Installing String Lines

Once all four batter boards are installed, select one of the abutments and lay a string line perpendicular across the center string line. The string line should cross over the center string line at the location of the begin/end-of-bridge form stakes with each end of the string line lying across the adjacent batter board. Holding one end of the string line where it intersects with the center line, pull the other end of the string line tight across the top of the batter board. Place a framing square inside the intersection of the two string lines and move the batter board end of the string until a right angle is achieved. Drive an 8d duplex nail into the top of the batter board where the string line crosses over it. Tie off the string line to the duplex nail using three to four wraps and two half hitches. Next, pull the opposite end of the string line taut across the other batter board. Again, place a framing square inside the intersection of the batter board and center string lines and move the batter board end of the string until a right angle is achieved. Drive an 8d duplex nail into the top of the batter board where the string line crosses over it. Pull the string line taut and tie off the batter board string line in the same fashion as the previous one. (See Figure 16.14.)

Using this method, the batter board string line is approximately perpendicular to the center string line. To ensure that it is at a true right angle, mark the center string line with a fine tipped felt pen where the batter board line crosses it. Then, measure a distance of 3 feet from that mark down the center string line toward

the opposite abutment and mark that location. Next, measure a distance of 4 feet down the batter board line toward the batter board and mark that location. Then, measure the distance diagonally between those two marks. If these two marks are at a right angle, the distance should be 5 feet. (See Figure 16.15.)

Note, due to the wear or damage that can happen to the hook of a tape measure, when using a cloth or steel tape, a more precise measurement can be achieved by “burning an inch.” “Burning an inch” means holding the end of the tape at 1 inch and measuring an inch longer at the other end of the tape. For example, if the measurement is 5 feet, measure from 1 inch to 5 feet, 1 inch. For all of the following layout measurements, use this “burn an inch” method.

If the diagonal measurement is not 5 feet, untie the batter board string line and move it along the top of the batter board until the 5-foot measurement is achieved. Reset the duplex nail at this location and retie the batter board string line. The batter board string line is now at a right angle to the center string line. It also now represents the end of the bridge.

Next, measure from the duplex nail anchoring the string line on top of the batter board to the batter board on the opposite bank abutment. This distance should be the total length of the bridge stringers previously identified. Once this measurement is achieved, drive an 8d duplex nail into the top of the opposite bank batter board to mark the location. Perform the same task on the batter boards on the opposite side of the abutment. Then tie a string line on one of the duplex nails and stretch it taut to the other and tie it off. This string line should be at a right angle to the center string line, but perform the 3-foot, 4-foot, and 5-foot measurements to be sure it is at a true right angle and correct as necessary. (See Figure 16.16.)

Next, measure the distance between the two batter board strings to ensure that it is the same as the intended bridge length. If not, make the necessary adjustments to the batter board string line until the correct distance is achieved. Then, to ensure that the batter board string lines on each abutment are square to each other, measure diagonally across the length of the bridge footprint to the ends of each line. (See Figure 16.17.) If both diagonals have the same measurement then the two batter board string lines are square to each other. If the diagonals are not of equal length, subtract the shorter measurement from the longer measurement and divide that number in half. To square up the batter board string lines, move the duplex nail attached to the string line with the shorter measurement (B) laterally outward and the duplex nail on the longer measurement (A) laterally inward by the calculated amount. (See Figure 16.18.)

For example, if one measurement is 36 feet and the other is 35 feet and 11 3/4 inches, the correction calculation is made as follows:

$$36 \text{ ft.} - 35 \text{ ft. } 11 \frac{3}{4} \text{ in.} = \frac{1}{4} \text{ in.}$$

$$\frac{1}{4} \text{ in.} \div 2 = \frac{1}{8} \text{ in.}$$

Thus, the shorter string line should be moved 1/8 inch outward and the longer string line moved 1/8 inch inward.

Repeat the diagonal measurement and continue to make adjustments to the duplex nails as necessary. When complete, the two batter board string lines should be equal distance from each other (length of bridge stringers) and square to each other. Remove the begin/end-of-bridge form stakes as they are no longer needed.

Note, if the abutment layout and batter board installation process is performed properly, very little adjustment will be required to square up the batter board string lines. Adjustments should be only fractions of an inch. When properly executed, installing batter boards and string lines will improve bridge construction production and quality.

It was previously discussed that the two batter board string lines represent the ends of the bridge stringers. When simple sills are being used, these string lines also represent the back edge of the sills. If additional sills are needed to provide the required bearing surface, they are placed forward of the back sill. Additional string lines can be added to the batter boards to identify the location of these sills by measuring along the batter board forward of the existing 8d duplex nail by the required layout distance and driving in another duplex nail. Perform this task on both batter boards. A second string line is then tied to one of the nails and stretched to the other one. It should be square to one previously installed. To ensure that these two lines are square to each other, measure diagonally to the ends of each line. (See Figure 16.19.) If both lines have the same measurement, then the two lines are square to each other. If not, follow the squaring up process previously discussed and illustrated in Figure 16.18.

A concrete abutment is often formed and poured to integrate a beam seat and a soil dam. For this type of layout, three batter board string lines are required: one to identify the end of the bridge stringers (back of the beam seat and front of the soil dam), one for the front of the concrete pour (front of beam seat), and one for the back of the soil dam. (See Figure 16.19.) Note, when installing the batter board string lines for a concrete abutment with a soil dam integrated into the pour, it is recommended that the distance between the two soil dams be increased an additional 1/2 to 3/4 inches beyond the length of the stringers. This additional distance will make it easier to place the bridge stringers between the two soil dams and will allow for air movement around the stringer ends.

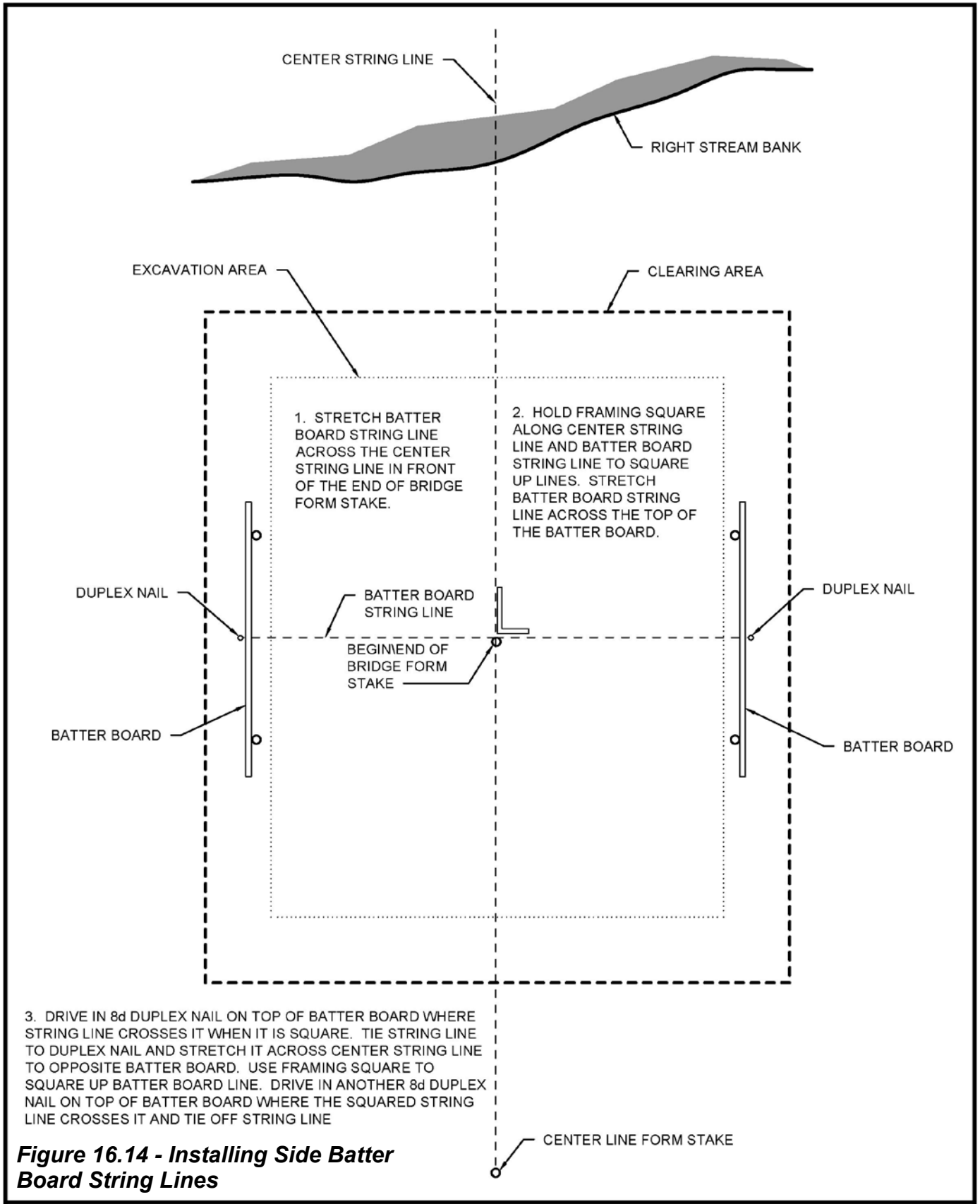


Figure 16.14 - Installing Side Batter Board String Lines

INSTALLING SIDE BATTER BOARD STRING LINES

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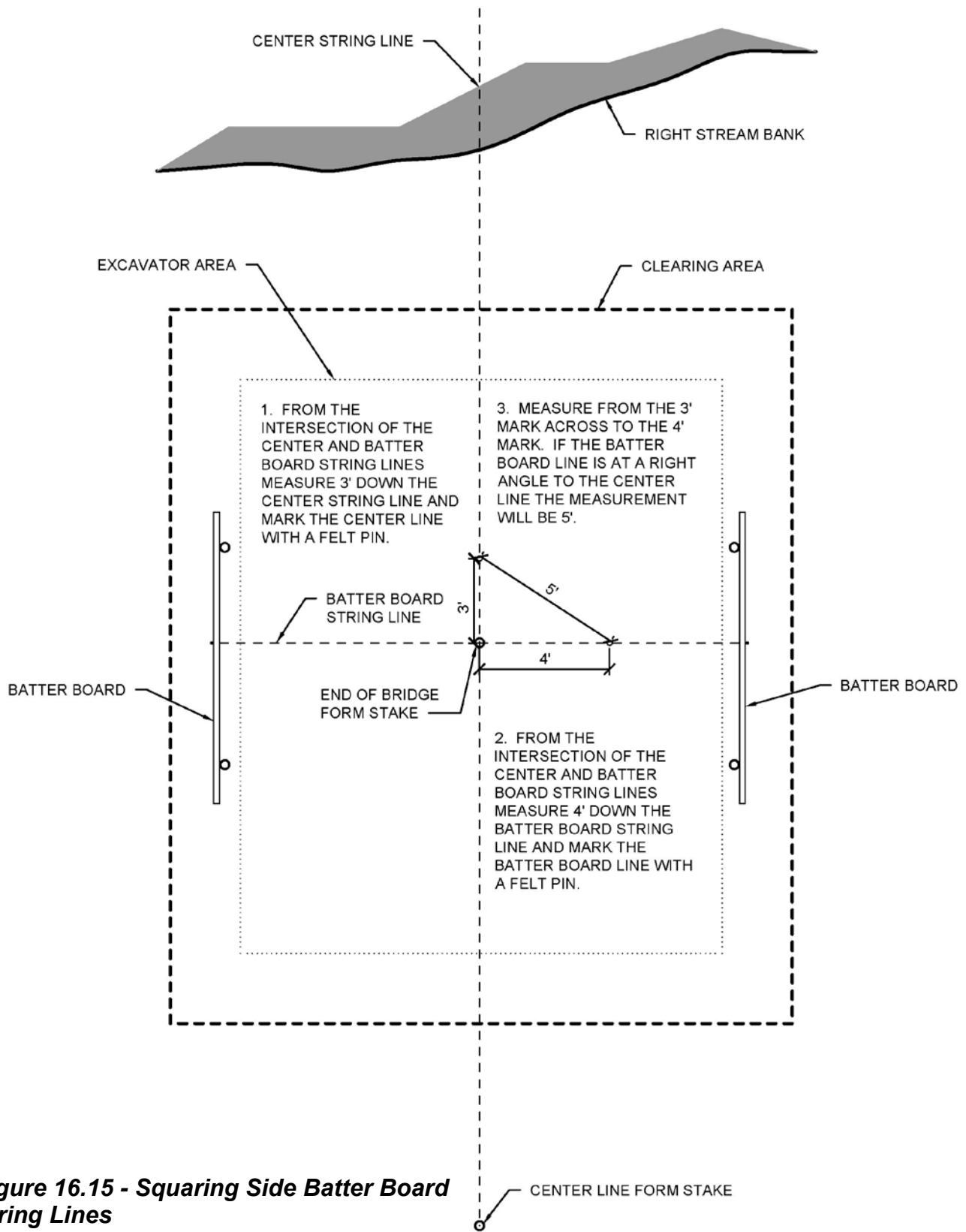


Figure 16.15 - Squaring Side Batter Board String Lines

SQUARING SIDE BATTER BOARD STRING LINES

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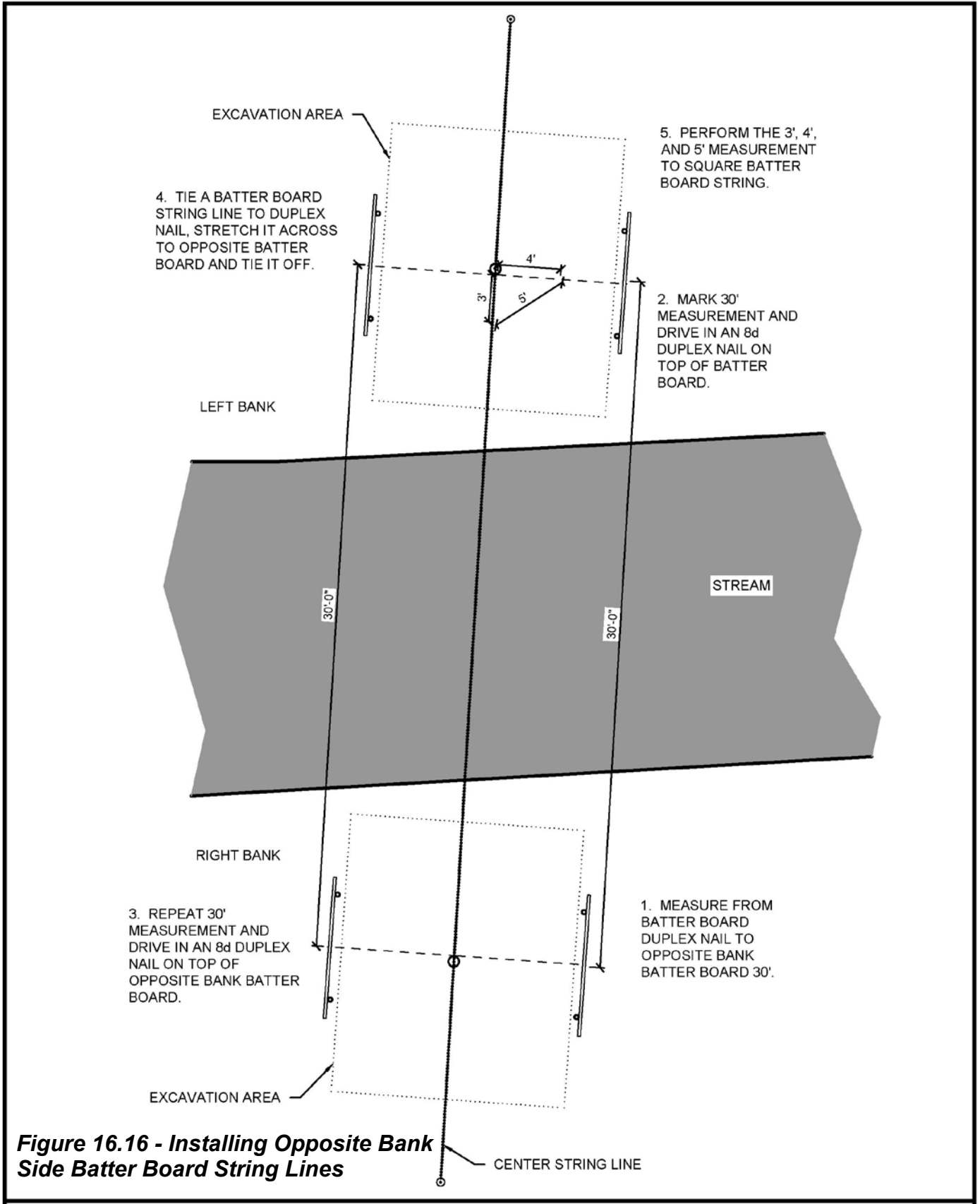


Figure 16.16 - Installing Opposite Bank Side Batter Board String Lines



INSTALLING OPPOSITE BANK SIDE BATTER BOARD STRING LINES

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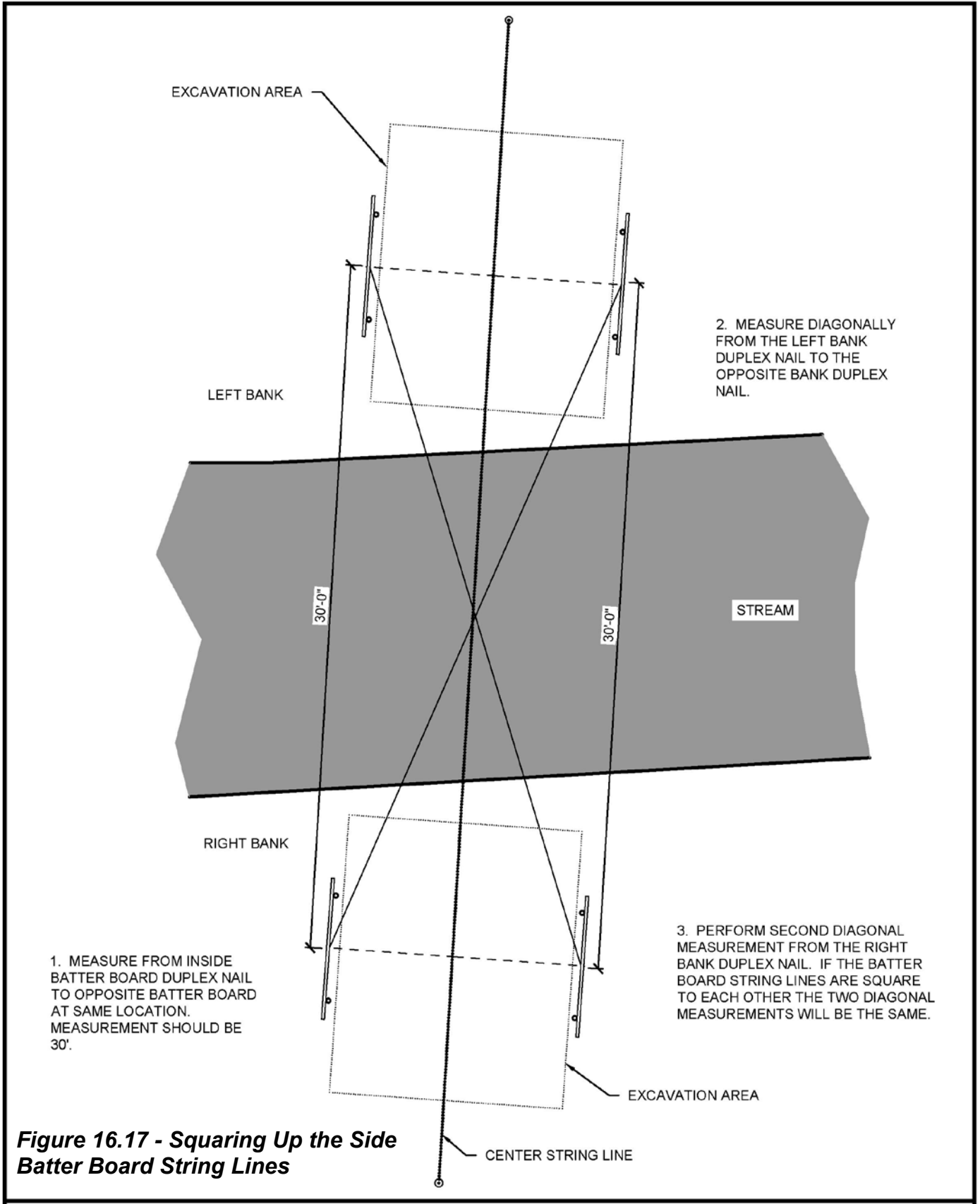


Figure 16.17 - Squaring Up the Side Batter Board String Lines



SQUARING UP THE SIDE BATTER BOARD STRING LINES

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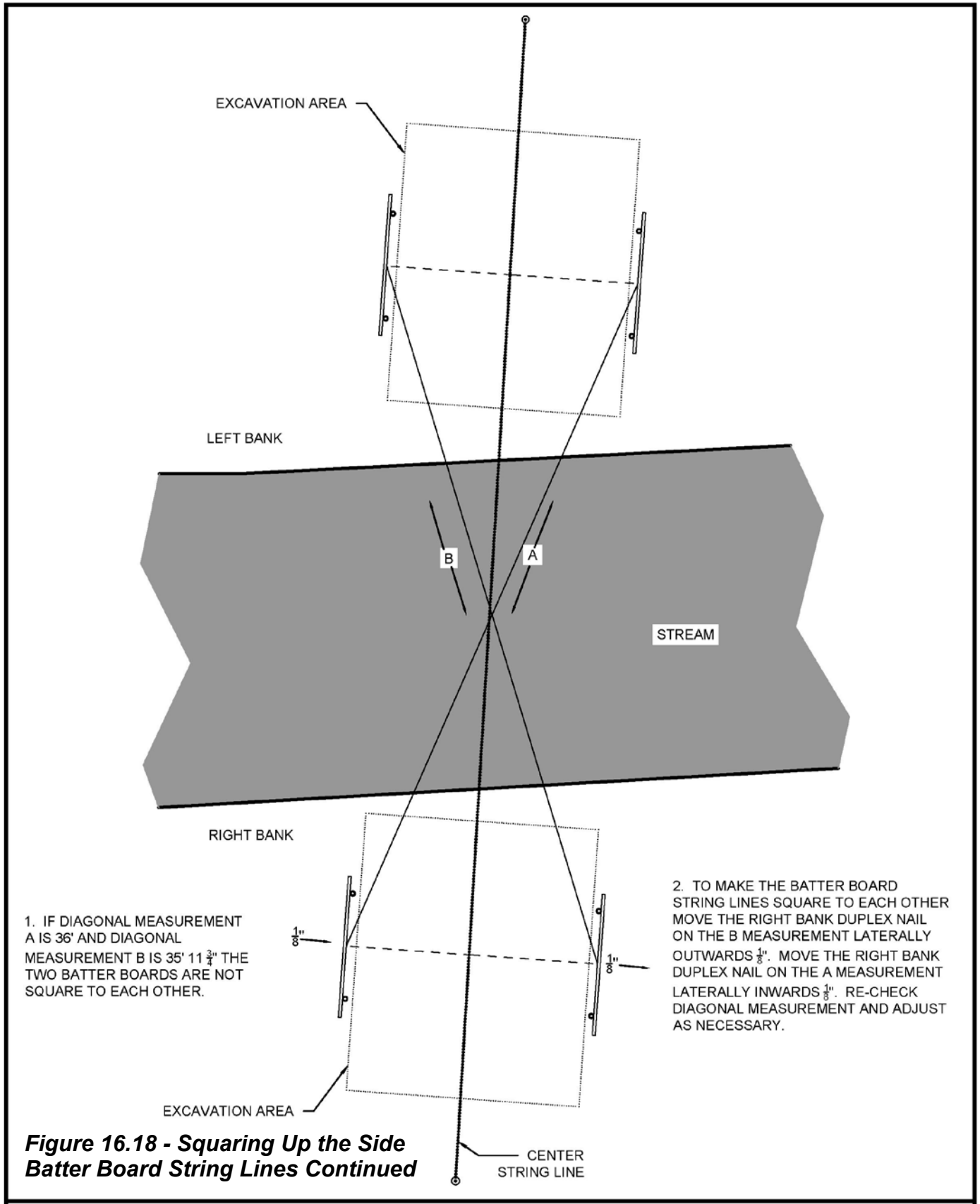


Figure 16.18 - Squaring Up the Side Batter Board String Lines Continued



SQUARING UP THE SIDE BATTER BOARD STRING LINES CONTINUED

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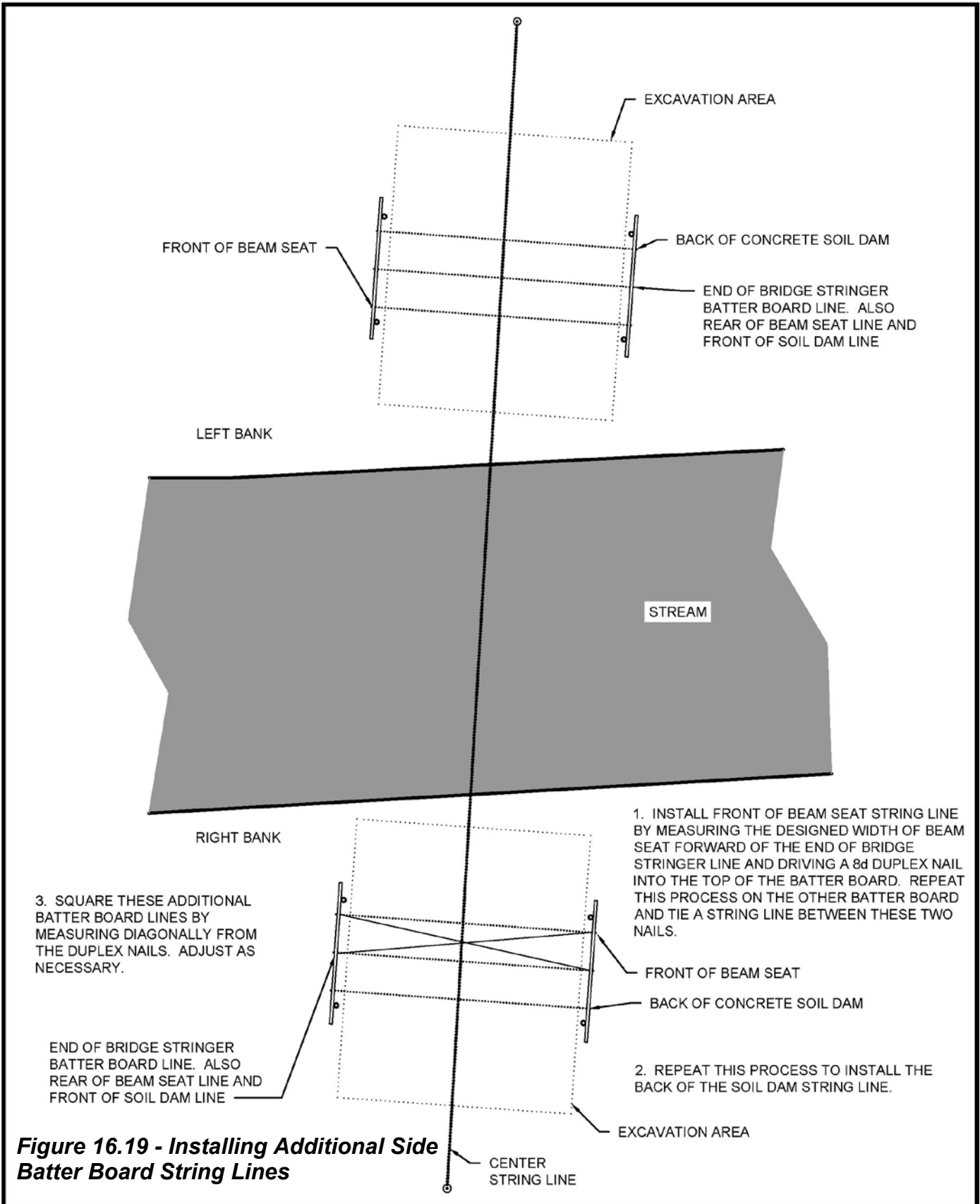


Figure 16.19 - Installing Additional Side Batter Board String Lines



INSTALLING ADDITIONAL SIDE BATTER BOARD STRING LINES

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16.6.1.3. Installing End Batter Boards

End batter boards are also used to facilitate the layout and squaring of more complex abutment structures such as formed concrete abutments. The batter boards are installed outside the ends of the abutment footprint so they do not interfere with construction of the abutments. String lines can be attached to the batter boards to identify the outside edge of the abutments, sills, J bolts, beam seat brackets, and bridge stringers. The end batter boards are installed in a fashion similar to the side batter boards. Note, if a concrete abutment with a stem wall is being constructed, the stem wall will project above the sill height and string lines cannot be installed to identify the J bolt and beam seat bracket locations.

Measure from the intersection of the center string line and the side batter board string line to the center line form stake and record that measurement. From the intersection of the side batter board string line and the center string line, measure 5 feet outward on the side batter board line and mark this location with a fine tipped felt pen. Note, a longer measurement may be required if the bridge abutments are wider than 12 feet. Perform the same task on the other side of the batter board string line. (See Figure 16.20.)

Using a cloth tape and a framing square, measure from the 5-foot mark on the side batter board string line the distance previously recorded (from the batter board string line to the center line form stake). Once the tape measure is at a right angle to the batter board string line and at the correct distance, drive a batter board form stake into the ground at that location. Repeat this process on the other side of the center line. Once both batter board form stakes are installed, secure a 12-foot batter board to the batter board form stakes and level it to the center string line in the same fashion as performed on the side batter boards. (See Figure 16.20) Repeat this process on the opposite abutment.

Now that the two end batter boards are in place, the center string line can be attached to the batter boards by scribing a pencil line across the batter boards where the center string line crosses over them. Then drive in 8d duplex nails into the center of the scribed lines and tie the center string line to the duplex nails. From the scribed center line on the batter boards, the layout for the outside edge of the stringers can be performed. (See Figure 16.21.) Also, the layout for the beam seat anchor bolts, beam seats, and the outside edges of the abutments can be performed. (See Figure 16.22.) Once the string lines used to layout these features are installed using duplex nails, perform the 3-foot, 4-foot, and 5-foot measurements to be sure they are at a true right angle.

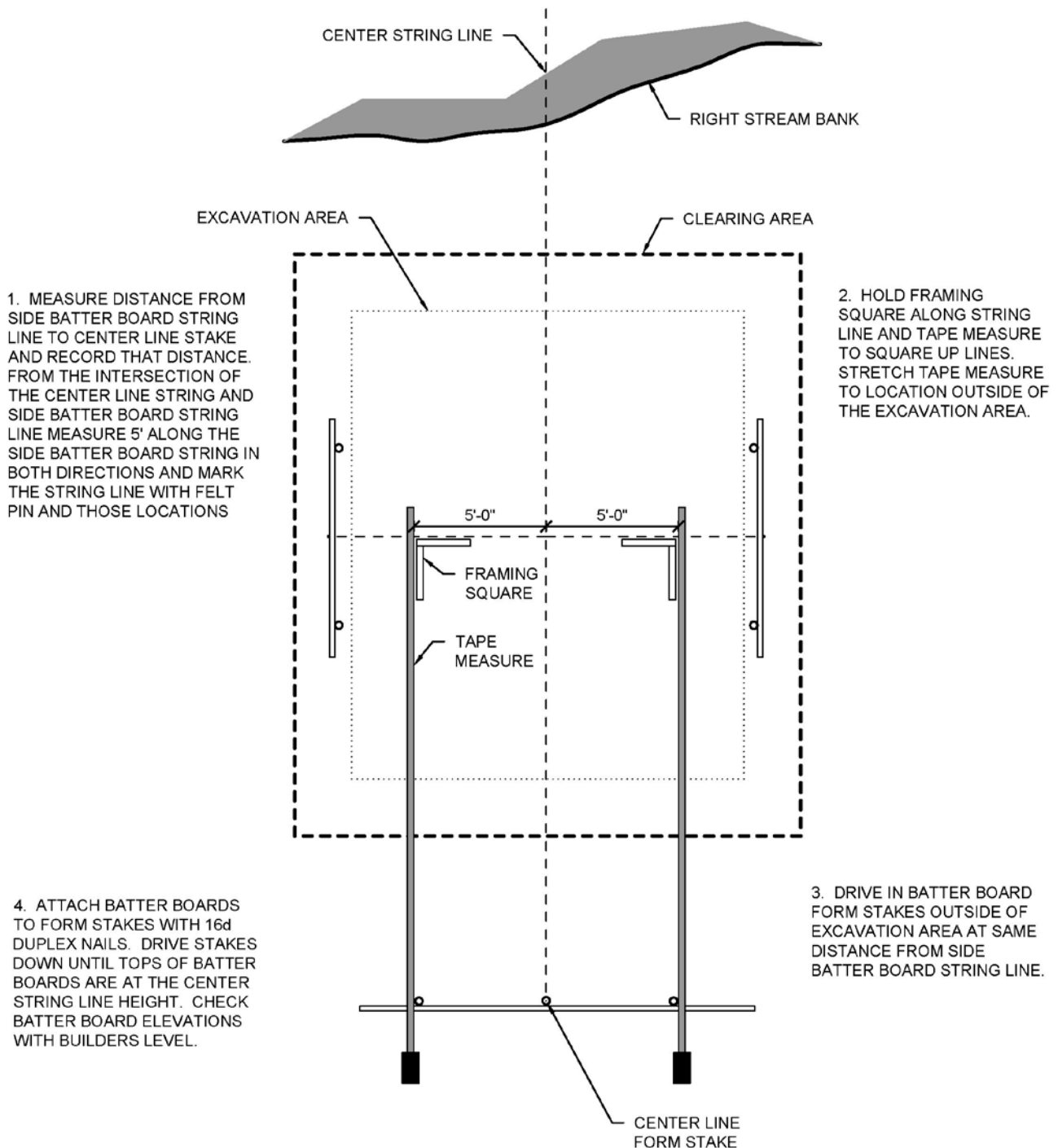


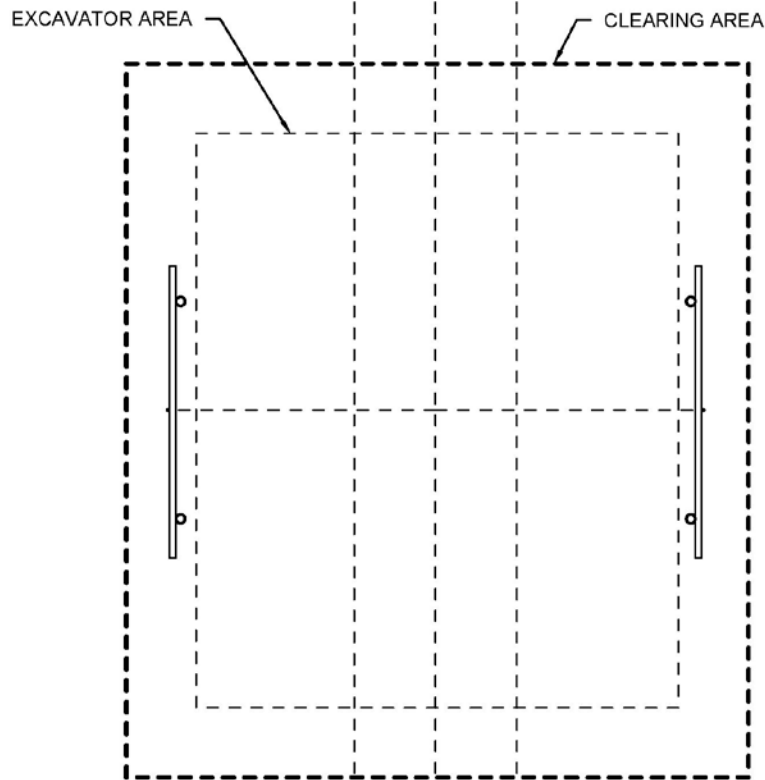
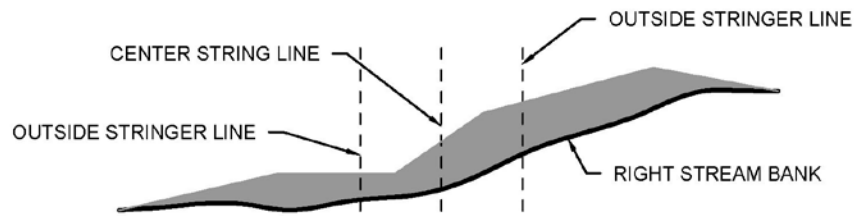
Figure 16.20 - Installing End Batter Boards



INSTALLING END BATTER BOARDS

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NOT TO SCALE



3. TIE STRING LINES TO DUPLEX NAILS AND STRETCH THEM TO THE OPPOSITE ABUTMENT END BATTER BOARD. REPEAT END BATTER BOARD STRING LINE INSTALLATION ON OPPOSITE BANK ABUTMENT AND TIE OFF STRING LINES TO DUPLEX NAILS.

2. MEASURE OUT FROM THE CENTER OF THE END BATTER BOARD 2'-6" SCRIBE LINES AND DRIVE IN 8d DUPLEX NAILS.

1. LOCATE CENTER OF END BATTER BOARD AND SCRIBE A LINE ACROSS THE TOP OF THE BOARD. DRIVE IN AN 8d DUPLEX NAIL AND TIE THE CENTER STRING LINE TO IT.

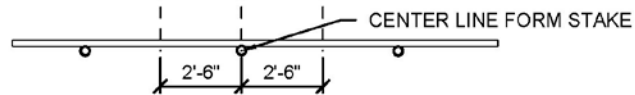


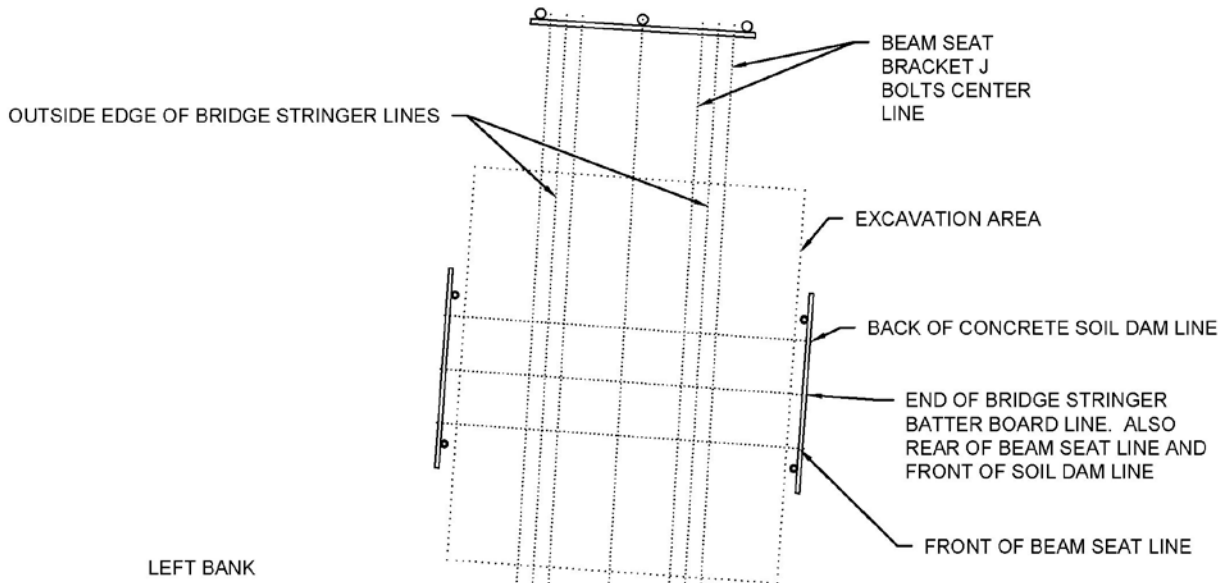
Figure 16.21 - Installing End Batter Board String Lines



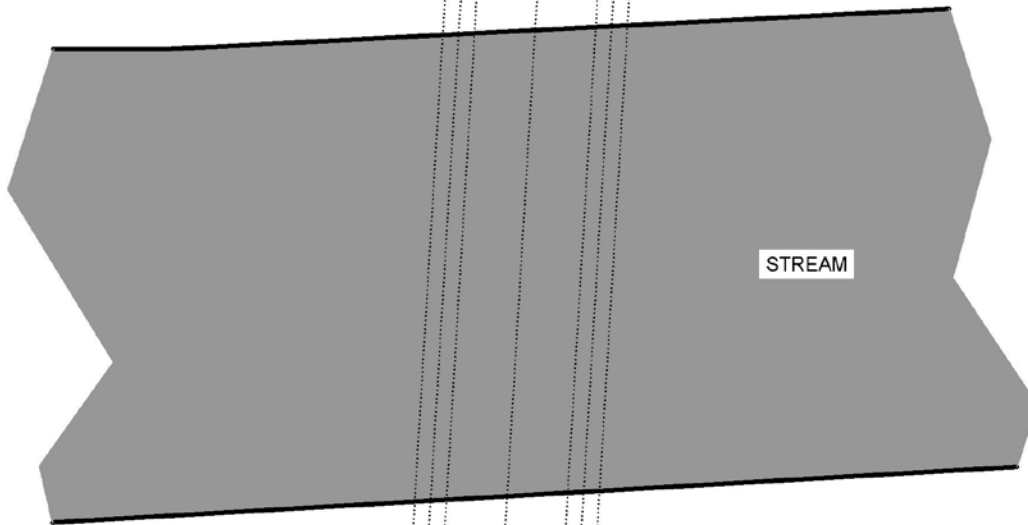
INSTALLING END BATTER BOARD STRING LINES

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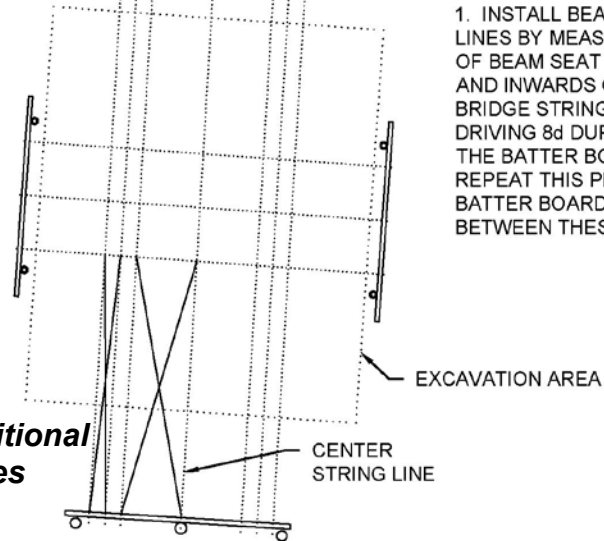
LEFT BANK



STREAM

RIGHT BANK

2. SQUARE THESE ADDITIONAL BATTER BOARD LINES BY MEASURING DIAGONALLY FROM THE DUPLEX NAILS TO THE INTERSECTIONS WITH THE SIDE BATTER BOARD STRING LINES. ADJUST AS NECESSARY.



1. INSTALL BEAM SEAT J BOLT CENTER LINES BY MEASURING THE DESIGNED WIDTH OF BEAM SEAT BRACKET HOLES OUTWARDS AND INWARDS OF THE OUTSIDE EDGE OF BRIDGE STRINGER STRING LINES AND DRIVING 8d DUPLEX NAILS INTO THE TOP OF THE BATTER BOARD AT THOSE LOCATIONS. REPEAT THIS PROCESS ON THE OTHER BATTER BOARD AND TIE STRING LINES BETWEEN THESE NAILS.

Figure 16.22 - Installing Additional End Batter Board String Lines



INSTALLING ADDITIONAL END BATTER BOARD STRING LINES

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NOT TO SCALE

16.6.1. Abutments Not Level to Each Other

If the two abutment sites are not level to each other, a decision must be made about how to bring the abutment foundations to the same elevation. This decision will be based on several factors: the amount of elevation required to keep the bridge above future flood events; the difficulty in excavating the abutment substrate; the amount of elevation difference between the abutments; and matching the approaching trail alignments. Depending on these factors, the options are: lower the higher abutment site via excavation; raise the lower abutment site with a retaining structure; or a combination of the two.

The initial layout for the bridge in the case of non-level abutments follows the same process previously discussed. Centerline and begin/end-of-bridge form stakes are installed, clearing and excavation limits are identified, and elevation profiles are shot and recorded for both abutment sites. Based on this information and the factors identified above, the abutments are constructed to the same elevation. Once constructed, the centerline and begin/end-of-bridge form stakes are reinstalled and the batter boards for both abutments can be installed as previously described. Note, since the original measurements were taken at a sloping angle (one end of the bridge higher than the other), the actual distance between the begin/end-of-bridge form stakes will be slightly shorter than the original measurement once the abutment foundations are level to each other.

16.6.2. Squaring Elevated Abutments

Sometimes both bridge abutment foundations are relatively level to each other but the abutments need to be elevated via a retaining structure to provide the necessary freeboard or match the approaching trail grade. The layout for these situations begins with the same batter board layout process as previously described. However, the string lines installed off of these batter boards identify the locations for the front of the retaining structure and the rear of the sills. The string lines marking the front of the retaining structures are used to identify their starting locations and to ensure that they are square to each other. In addition, identifying the sill locations ensures that the foundations of the abutments are large enough to square up and install the bridge sills at the designed distance apart. Once construction of the abutments begins, the string lines identifying the sills are removed since they are no longer necessary. If both abutments are constructed at the same time, they are frequently squared to each other by taking diagonal measurements. If one abutment is constructed first, the second abutment is squared to it as it is constructed. Elevations are monitored with an auto level. When both abutments are complete they should be square and level to each other, at the appropriate height, and have the depth and width to accommodate the designed sills. The sills are placed at the appropriate distance apart and squared to each other using the methods previously described.

16.7. Abutment Construction

16.7.1. Earthen Abutments

The processes and methods for constructing an earthen abutment were previously described in this chapter.

16.7.2. Soil/Rock Retention Abutments

The processes and methods for constructing a variety of soil/rock retention abutments were discussed in Chapter 13, *Retaining Structures*.

16.7.3. Concrete Abutments

A concrete abutment can be relatively simple or very complex depending on the design. A large, complex abutment should be designed and approved by a licensed engineer. To facilitate the discussion on how to construct a concrete abutment, a simple design with a “cold joint footing” will be used.

16.7.3.1. Site Preparation

A concrete abutment requires a solid foundation. If the abutment is to be poured on top of native soil, the foundation must be properly excavated and compacted as previously described. In addition, the abutment must be properly laid out. Layout and squaring of bridge abutments was described previously.

16.7.3.2. Abutment Design and Construction

A simple concrete abutment usually has a footing to provide a stable base. The base of the footing must have sufficient area to support the load of the bridge. The footing must also be long and wide enough to accommodate the depth and width of the stem wall. The footing can be formed and poured separately (“cold joint”) or it can be formed and poured as a unit with the rest of the abutment.

A stem wall is formed and poured on top of the footing. It must be wider than the outside to outside measurement of the bridge stringers and high enough to be level with the top of the decking. Formed within the stem wall is the beam seat upon which the bridge stringers will rest. The rest of the stem wall extends above the beam seat and acts as a soil dam. This section of the stem wall provides the barrier between the surrounding soil and the bridge superstructure. (See Photo 16.28.)



Photo 16.28 - Concrete Bridge Abutment with Stem Wall/Soil Dam

Use the following process to design the layout of an abutment stem wall poured on top of a footing.

1. Determine the minimum **width** of the stem wall using the following formula:

$$\begin{aligned} \text{Width} &= \text{Outside to Outside Stringer Width} + 2 \text{ ft.}^* \\ \text{Width} &= 5 \text{ ft.} + 2 \text{ ft.} = 7 \text{ ft.} \end{aligned}$$

*The additional 2 feet are required to maintain an adequate distance from the outside of the abutment form to the J bolts used to anchor the stringer brackets. If the J bolts are too close to the edge, they can fracture and spall off the edge of the concrete form when put under stress.

2. To determine the **height** of the stem wall, use the following formula:

$$\begin{aligned} \text{Stem Wall Height} &= \text{Beam Seat Height}^1 + \text{Soil Dam Height}^2 - \text{Footing Height}^3 \\ \text{SWH} &= 3 \text{ ft.} + 1 \text{ ft. } 9.5 \text{ in.} - 1 \text{ ft.} = 3 \text{ ft. } 9.5 \text{ in.} \end{aligned}$$

(1) The designed height of the beam seat, which is the distance from the bottom of bridge stringers to the excavated earthen pad. This information is based on the layout of the bridge site.

(2) The height of the soil dam, which is based on the thickness of the metal brackets used to attach the stringers to the beam seat; the height of the bridge stringers; and the thickness of the decking material.

(3) The height of the footing above the excavated earthen pad.

Note, some bridge manufacturers require an elastomeric pad between the bridge stringers and the beam seat brackets. If such a pad is required, its thickness must be added to the beam seat bracket height to determine the correct stem wall height.

3. To determine the **thickness** of the stem wall, use the following formula:

$$\begin{aligned}\text{Stem Wall Thickness} &= \text{Beam Seat Width} + \text{Soil Dam Width} \\ \text{SWT} &= 12 \text{ in.} + 12 \text{ in.} = 24 \text{ in.}\end{aligned}$$

The beam seat and soil dam widths identified are the minimum recommended dimensions for this sample abutment design. These dimensions provide the surface area necessary to support the bridge stringers and soil dam width and ensure structural integrity. If the soil dam is too thin, it can be damaged if struck by the bridge stringers when they are installed.

Note, the dimensions of this stem wall are hypothetical, the dimensions of concrete abutments must coincide with the site design and the loading and stresses associated with the bridge structure. A qualified engineer should be consulted when developing concrete abutment plans.

Based on these dimensions, a set of plans for the entire abutment can be developed. Whether an engineer or architect draws the plans or they are done in-house, a detailed design for how the abutment will be assembled is needed. The exact dimensions of the abutment, the measurements of the various form boards, and the layout for the reinforcement steel, snap ties, and all thread are needed. Without this level of detail, fabricating and assembling the abutment forms will be difficult.

16.7.3.3. Forming the Abutment

A footing can be constructed below or above grade. The simplest footing is a trench dug into the ground to the specified length, width, and depth. In locations that freeze during winter, the footing must be excavated below the frost line (i.e., excavate below the depth to which the soil will freeze). Local building codes usually specify this depth. If the ground is level, the trench can be filled with concrete once the reinforcement steel has been installed. For this discussion, the footing will be formed above ground.

Because a footing is usually a low profile structure, forming the footing is relatively simple. It is recommended that the footing be a minimum of 12 inches deep. It can be formed using 3/4-inch exterior grade plywood for the front, back, and sides of the form. The plywood is joined at the corners through the use of plywood cleats or Simpson tie straps. (See Figures 16.23 and 16.24.) Use the batter board string lines to ensure that the footing forms are at the correct

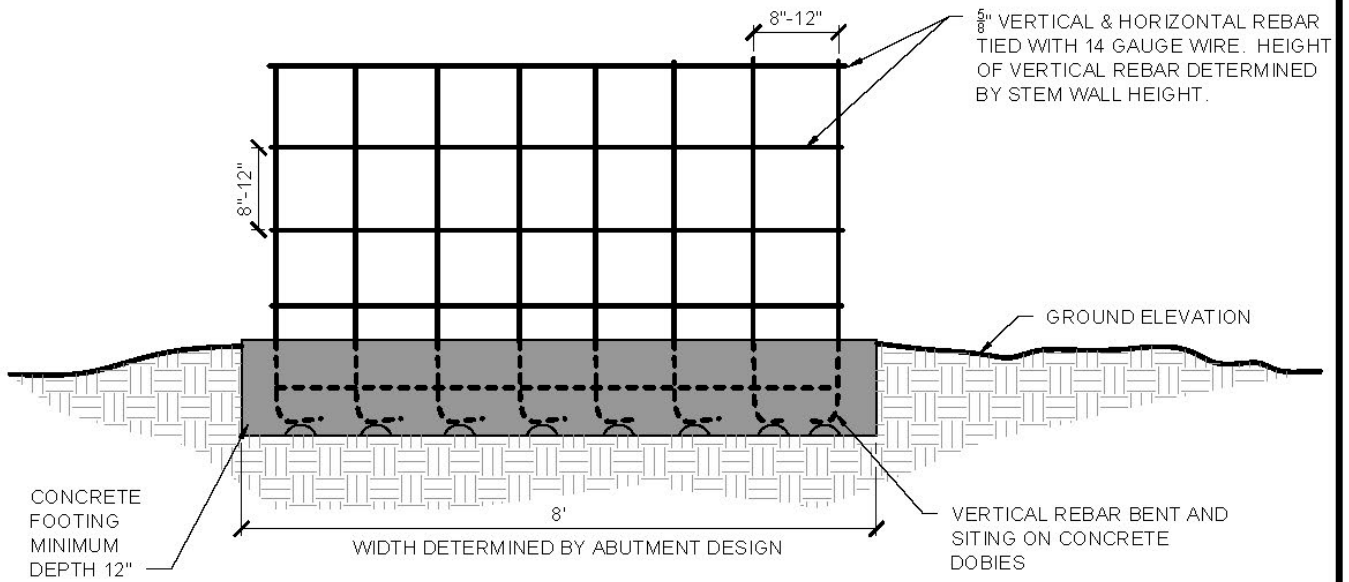
locations and square to the center line. Place a framing square along the inside corners of the form to ensure that they are at right angles to each other. Secure the footing forms by driving metal form stakes into the ground next to the corners and driving 16d duplex nails through the form stakes and into the plywood. Additional wooden stakes and braces can also be installed to secure the form boards. Ensure the height of the footing form is equal all the way around the form by using a 4-foot carpenter's level or an auto level and a stadia rod.

Once the footing forms are level and well-anchored, the interior of the forms should be painted with concrete form oil to keep the concrete from sticking to the form boards and to facilitate their removal once the concrete is cured.

Next, install the reinforcement steel by placing rows of 5/8-inch diameter rebar vertically on top of concrete dobies. The number of rows of rebar is based on the width of the form, and the length of the rebar is based on the height of the stem wall forms. Individual lengths of rebar are placed 8 to 12 inches apart and the bottom of each is bent at a 90 degree angle using a manual rebar cutter and bender. Since the form boards have not been installed yet, the plans for the abutment will be used to determine the number and length of rebar required. (See Figures 16.23 and 16.24.) The ends of the rebar should be a minimum of 2 inches from the edges of the form boards.

Next, horizontal rebar is installed. It is also installed so individual bars are placed 8 inches to 12 inches apart with the ends being no closer than 2 inches from the sides or top of the form boards. The horizontal rebar is tied off to the vertical rebar using 14 gauge galvanized wire. (See Figures 16.23 and 16.24.) When installing the reinforcement steel, make sure the rebar does not interfere with the future placement of the J bolts used to anchor the stringer brackets to the beam seat. Once all the rebar has been installed, a minimum of two wood cleats should be nailed across the top of the footing forms to keep them from spreading apart. Metal Simpson strap ties can also be used for this purpose.

FOOTING CONSTRUCTED BELOW GRADE FRONT VIEW



FOOTING FORMED & CONSTRUCTED ABOVE GRADE FRONT VIEW

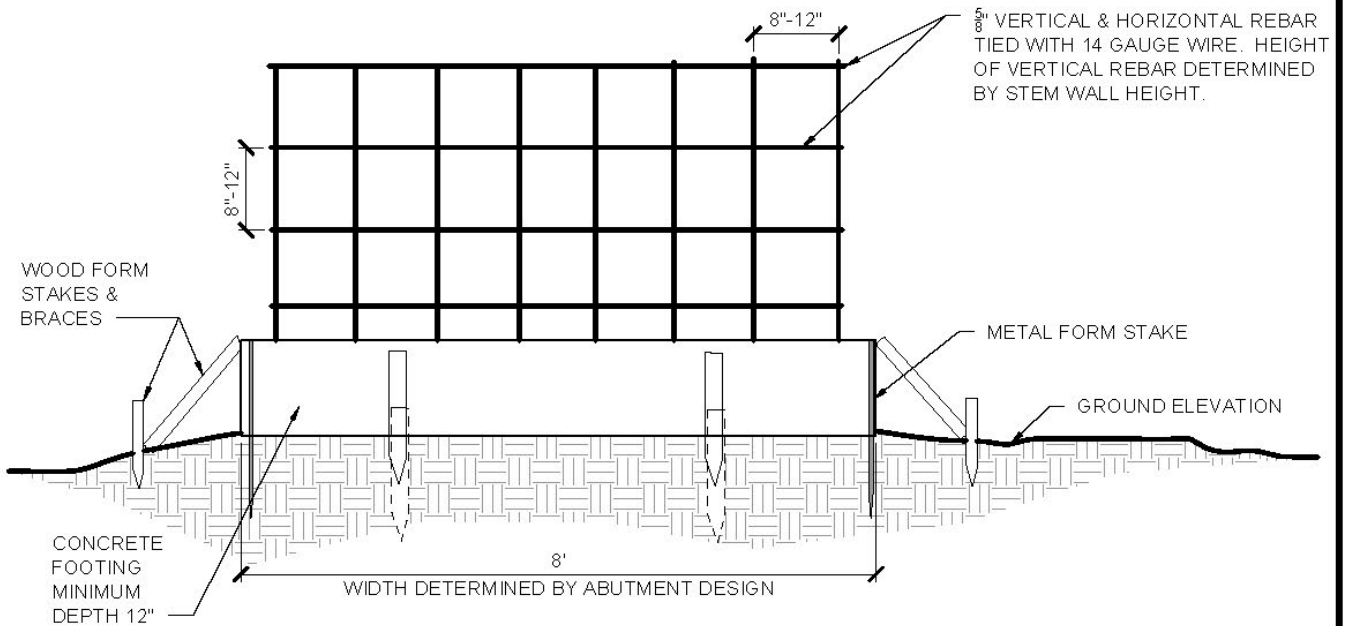


Figure 16.23 - Concrete Footings

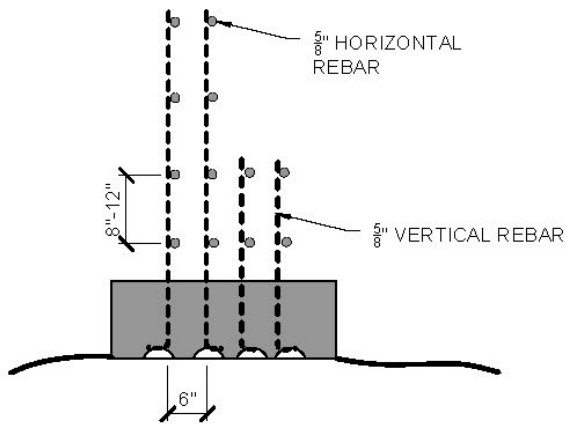


CONCRETE FOOTINGS
CALIFORNIA STATE PARKS

NOT TO SCALE

FOOTING FORMED &
CONSTRUCTED

ABOVE GRADE END VIEW



FOOTING FORMED &
CONSTRUCTED

ABOVE GRADE TOP VIEW

3/4" PLYWOOD CLEATS
ATTACHED TO END FORM
BOARD WITH WOOD
SCREWS

PLYWOOD CLEAT NAILED ON TOP
OF FORMS WITH 16d NAILS TO
PREVENT SPREADING

FRONT OF FOOTING
FORM 3/4" PLYWOOD

BACK OF FOOTING
FORM 3/4" PLYWOOD

16d DUPLEX

END OF FOOTING
FORM 3/4" PLYWOOD



SIMPSON TIE STRAP

Figure 16.24 - Concrete Footings Continued



CONCRETE FOOTINGS CONTINUED

CALIFORNIA STATE PARKS

NOT TO SCALE

16.7.3.4. Pouring the Footing

If the bridge will be located near a trailhead, it may be possible to deliver the concrete in a concrete truck (“transit mix”) or dump trailer. This concrete can then be put into a concrete pump hopper and pumped to the abutment site. Most concrete pumps have a limit of around 250 feet on level ground, which restricts the use of this system. When pumping a long distance, the concrete mix may need to be wetter to facilitate movement through the hose, which may conflict with the concrete mix prescription or pouring process. Wet concrete takes longer to cure, can be difficult to place, and produces a weaker concrete structure.

When receiving transit mix, a slump test should be performed to check the consistency of the concrete. The consistency is the relative stiffness of the concrete. It also indicates how much water has been used in the mix. Too much water and the concrete will be weak. Too little water and the concrete will be difficult to work and will set-up too fast.

A slump test is performed by filling a slump cone (or Abrams cone) with the wet concrete. The mold is shaped like a cone that is missing the pointed end. Wet the inside of the cone before filling it with concrete and place the cone on a hard, non-absorbent surface. Fill one-third of the cone’s volume with concrete, “rod” the concrete with a 5/8-inch diameter metal rod, and tamp the concrete about 25 times to remove air bubbles and settle the concrete. Then, fill the cone to two-thirds of the volume and rod this layer another 25 times with the bottom of the rod only penetrating the surface of the lower concrete layer. Next, fill the cone to the top and rod this layer 25 times, only penetrating the surface of the middle concrete layer. Level-off the concrete spilling over the top of the mold. Carefully lift the cone upward with a twisting motion so as to not disturb the cone of concrete. Place the cone next to the concrete. Without the support from the mold, the concrete should slump under its own weight.

The metal rod is placed horizontally across the top of the mold and extended over the slumped pile of concrete. Measure the distance between the bottom of the rod and the top of the concrete to determine the height lost when the concrete slumped. The height lost, expressed in inches, is the “slump” for that particular batch of concrete. (See Figure 16.25.) A slump of 1 to 3 inches indicates a very stiff mix, suitable for commercial work. A stiff mix is difficult to work and ordinarily requires a mechanical vibrator to consolidate properly. It produces the hardest and strongest concrete. A slump of 4 to 5 inches is easier to pour and is acceptable for residential work. It can be worked by hand and it still results in strong concrete. Any mix with a slump of more than 7 inches should not be used.

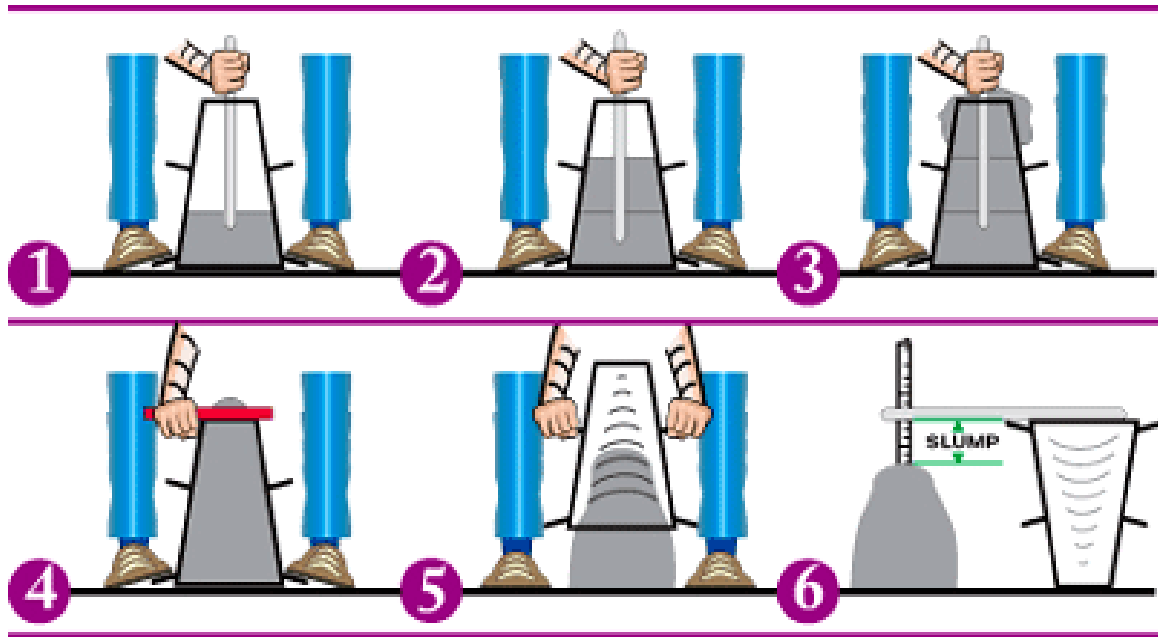


Figure 16.25 - Slump Test Method

Helicopters can also be used to transport wet concrete to remote bridge sites. The timing in handling, delivering, and installing of wet concrete is critical. This method of delivery is also very expensive and sites may lack the overhead access necessary for delivery by helicopter. For a remote location, sacks of dry ready mix concrete can be transported to the bridge site by helicopter, pack stock, trail cart, toter, or hand packing. Ready mix concrete comes in 60 or 80 pound bags. The size of the bag selected for use should depend largely on the method of transportation.

When selecting ready mix concrete for bridge abutments, the standard 4,000 pounds per square inch (PSI) mix is adequate for most jobs. When a greater strength and quicker curing are required, the 5,000 psi mix is preferable. In areas subject to winter freezes, an air entrainment additive is recommended.

Once the ready mix is on-site, it should be placed on a water proof tarp and covered with another tarp to keep moisture from setting up the concrete prematurely. Straw wattles or silt fences must be placed around the bags of concrete to prevent the cement from migrating into the nearby watercourse. Additional straw wattles must be installed around the abutment and concrete mixing sites to contain concrete spilled during the mixing and pouring processes.

To mix the concrete, a steady supply of water must be available. Usually a hose can be used to pipe water from an upstream site to the abutment. The use of local water supplies and the method of transportation must be approved in the environmental review and permitting process. Before mixing the concrete, the soil at the bottom of the footing must be wetted down to prevent the soil from drawing water out of the concrete, which could cause it set-up too fast and

weaken. Usually two or more wheelbarrows are used to mix the water and concrete and maintain a steady supply of mixed concrete to the abutment. Concrete and water are mixed together in a wheelbarrow with a concrete hoe until they are thoroughly mixed and have the right consistency (i.e., stiff but still slumps approximately 2 to 5 inches). The concrete is then transferred to the abutment forms in 5 gallon plastic buckets. It is poured into the forms in a manner that keeps the concrete evenly distributed. A piece of rebar is used to rod the concrete (agitate) and facilitate its distribution. If permitted, a concrete vibrator can be used to agitate the concrete to eliminate pockets or voids in the concrete and ensure that it has a uniform consistency. A 2500 watt generator is needed to supply power to a vibrator. The vibrator should be used with caution as too much agitation of the concrete can lead to segregation of the aggregate and form failures.

Once the form is filled, use a trowel to strike-off excess concrete. The rebar projecting through the concrete will prohibit the use of a board to strike off the top of the pour. Once the concrete begins to set, an edger can be used around the top of the form boards to ease the future removal of the forms. The exposed concrete should be covered with wet fabric to prevent the concrete from curing too fast, which can lead to the formation of cracks in the concrete. The non-woven geotextile fabric used in the Best Management Practices at the bridge site will work well for this purpose. The concrete should be allowed to cure for several days before the form boards are removed.

16.7.3.5. Forming the Stem Wall

The reinforcement steel for the stem wall was installed as part of the footing construction. (See Figure 16.26.) Following the plans for the abutment, cut out and assemble the stem wall form boards. (See Figure 16.27.) Exterior-grade plywood (CDX) 3/4 inch thick should be used to construct the concrete forms. Using the plans, the back of the plywood form should require one piece of plywood, 7 feet 11.5 inches wide and 3 feet 9 inches high. The front of the form should require two pieces of plywood: one 7 feet 1.5 inches wide and 1 foot 11.5 inches high, and one 7 feet 11.5 inches wide and 1 foot 9.5 inches high. Layout and cut the plywood so that the smooth side (C side of plywood) will be on the inside of the form to reduce the amount of concrete sticking to the plywood and prevent deformities when the forms are removed. The sides of the form should require two pieces of plywood 3 feet 9 inches high and 2 feet 3 inches wide. Two L shaped boards are cut out of these pieces of plywood per the plan's dimensions. (See Figure 16.27.) The side forms are cut an extra 3 inches wide to allow for the thickness of the plywood when joined with the front and back pieces and the 3/4-inch-thick plywood strips that will be fastened along the edges to keep the end pieces aligned with the front and back plywood forms. (See Figure 16.27.)

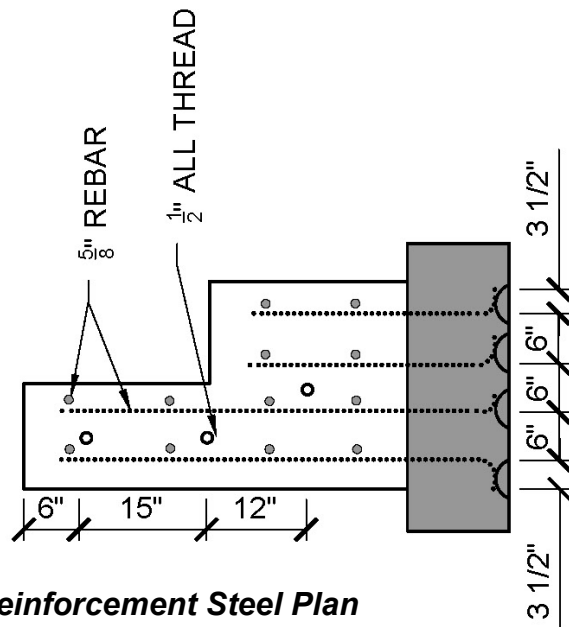
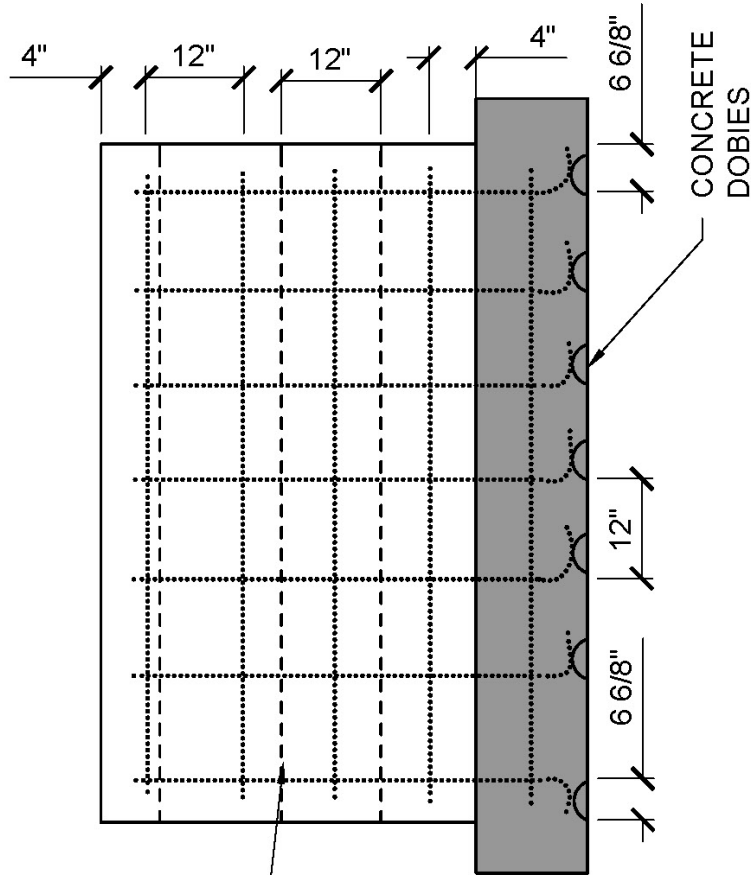


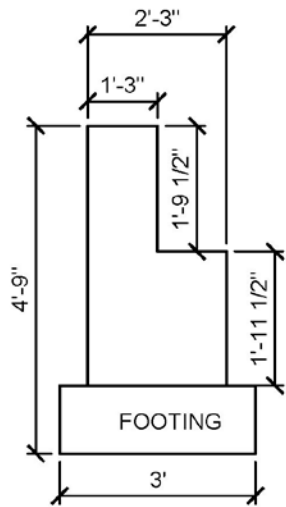
Figure 16.26 - Reinforcement Steel Plan



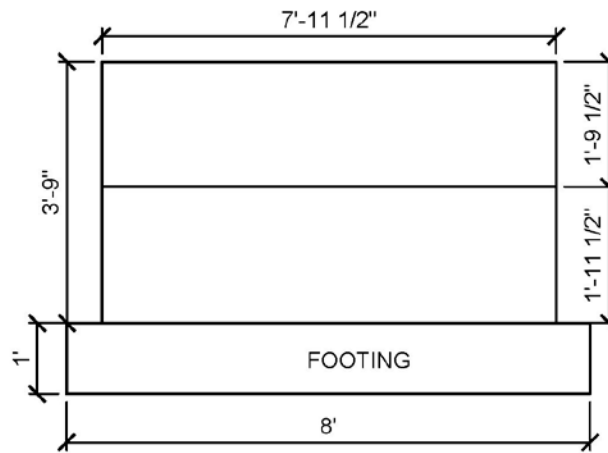
REINFORCEMENT STEEL PLAN

CALIFORNIA STATE PARKS

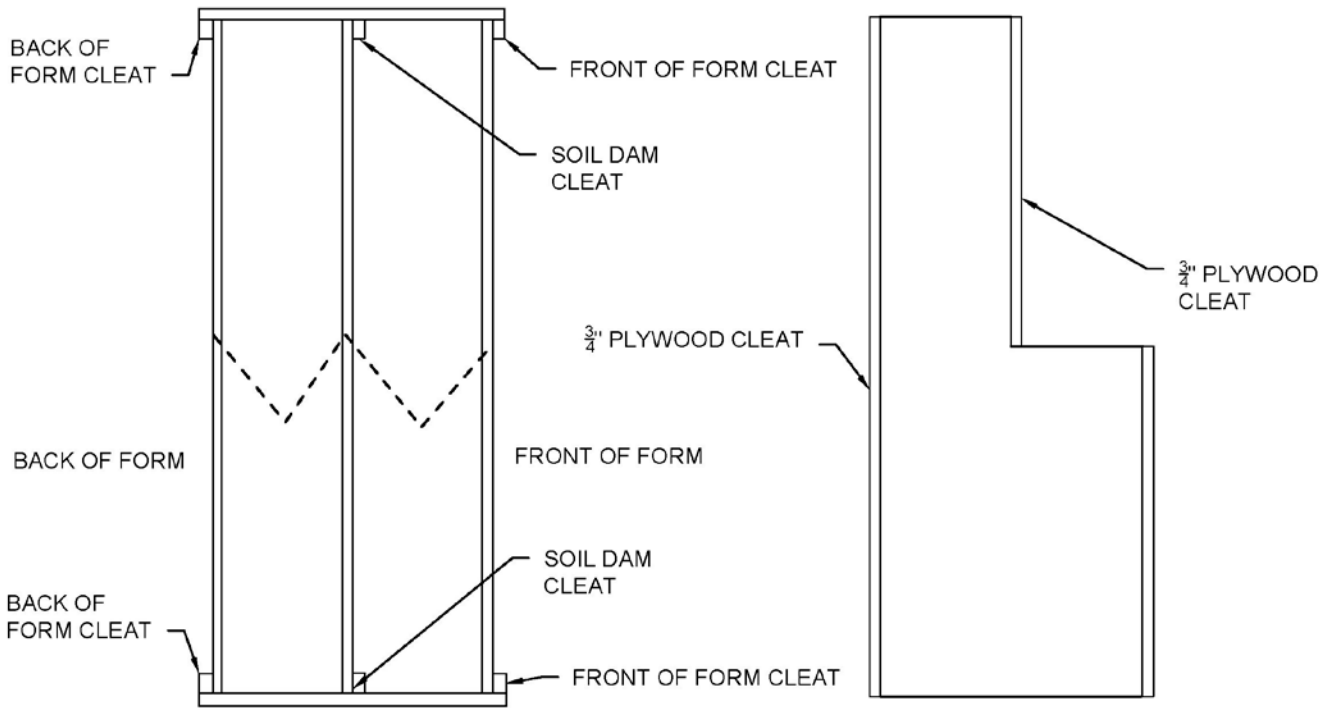
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FORM DIMENSIONS
END VIEW



FORM DIMENSIONS
FRONT VIEW



ATTACHMENT OF SIDES

ATTACHMENT OF SIDES

OVERHEAD VIEW

END VIEW (INSIDE)

Figure 16.27 - Concrete Abutment Form Plan



CONCRETE ABUTMENT FORM PLAN

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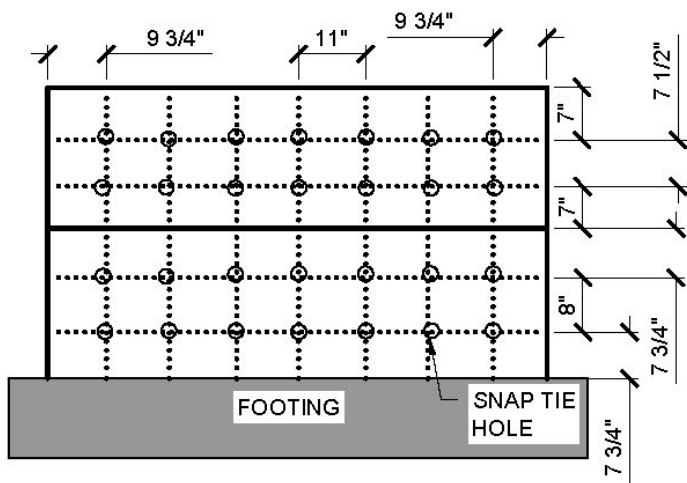
NOT TO SCALE

Once all the back, front, and side pieces are cut out, the layout for the snap ties and all thread can proceed. (See Figure 16.28.) Snap ties are used to connect the front and back forms together and to keep them from bulging, spreading, or separating when filled with concrete. The all thread is used to perform the same task on the end form pieces. When developing the plan for laying out these fasteners, account for the layout of the reinforcement steel and J bolts. The maximum distance between snap ties should be 16 inches when a 3/4-inch plywood sheet is used horizontally and 24 inches when it is used vertically. Snap ties come in varying lengths. The length needed should coincide with the inside front to back measurement of the forms. All thread (1/2-inch diameter) can be purchased in 20-foot long pieces and cut to the length required.

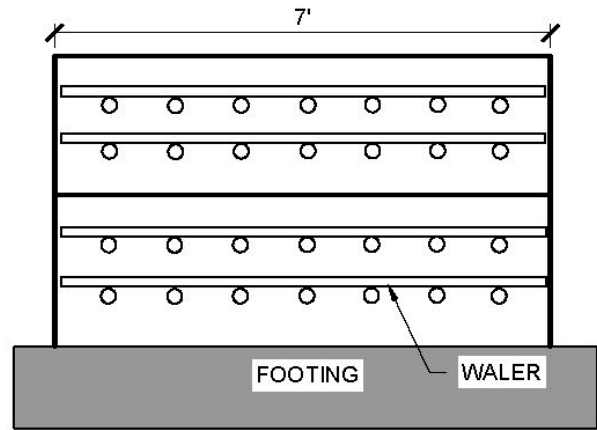
When drilling the holes for the snap ties, it is best to lay the front and back form board pieces on top of each other. Next, perform the layout for the drill holes and drill 5/8-inch diameter holes through both form boards at the same time. Ensure that the snap tie drill holes will match when the snap ties are installed later by having the front and back pieces together. The same process should be used for drilling the 1/2-inch diameter all thread holes for the end form pieces. Next attach the 3/4-inch plywood strips along the vertical edges of the end boards using 1 1/4-inch wood screws. Once these tasks are complete, apply oil to the inside of the form boards.

After the form boards are drilled they can be assembled. Start with the front and back forms. Set them on the concrete footing at the designed locations and begin inserting the snap ties. Start at the bottom snap tie row of the forms. The snap ties will have to be installed from the inside of the form boards. Insert one end of a snap tie into a drill hole in the back form board and then insert the other end into the corresponding hole in the front form board. This process will require working the snap ties around the reinforcement steel. It is sometimes easier to lay the entire row of snap ties across the rebar at the appropriate locations prior to inserting the snap ties. Once the ends of the snap ties are through both form boards, slip a snap tie bracket over each end to keep them from being pulled back through the holes. Perform this same installation process on the next row and continue until all the snap ties are installed.

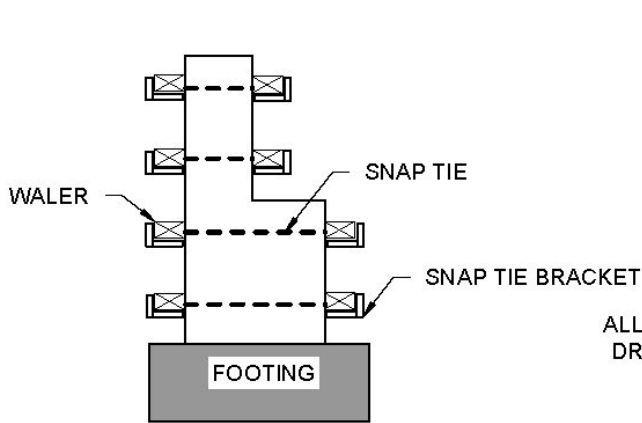
Another technique is to insert all the snap ties in the front or back form board, then slide all the snap ties through the rebar at the same time. Once the snap ties are through the rebar and the form board is at the appropriate location, the other form board is held into place and the ends of the snap ties are pushed through the pre-drilled holes.



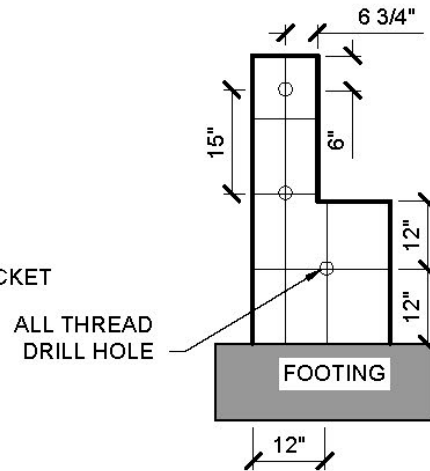
SNAP TIE DRILL HOLE SCHEDULE
FRONT VIEW



WALER LAYOUT
FRONT VIEW



SNAP TIE, WALER & SNAP BRACKET DETAIL
END VIEW



ALL THREAD DRILL HOLE SCHEDULE
END VIEW

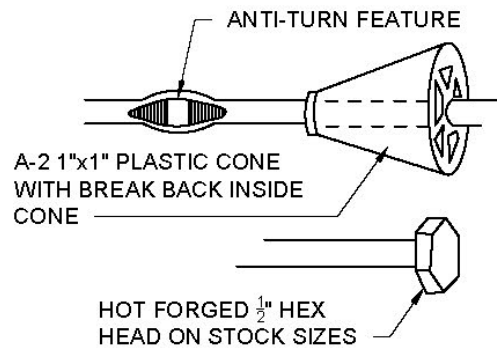


Figure 16.28 - Snap Tie and All Thread Plan



SNAP TIE & ALL THREAD PLAN

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NOT TO SCALE

The 2- x 4-inch waler boards are installed next starting on the lowest row of snap ties. The boards are laid across the top of the snap ties (4-inch side horizontal or facing up) and inserted between the snap tie bracket and the form board. (See Figure 16.28.) Once one side of the form is completed, install the waler board on the opposite side. Once both sides are completed, tighten the form brackets. On the snap tie bracket there is a metal wedge that can be tapped with a hammer to tighten the bracket against the waler board. Tighten the brackets against the waler board so they hold the waler firmly in place. Do not over-tighten the brackets because it can make the assembly of the other waler boards more difficult.

Next, install the waler boards on the top row of snap ties following the same process. Installing the bottom and top rows first helps line-up and unitize the form boards and allows the form to be a free-standing structure, which expedites the installation of the remaining waler boards. Once the top row is completed, install the waler boards on the middle row.

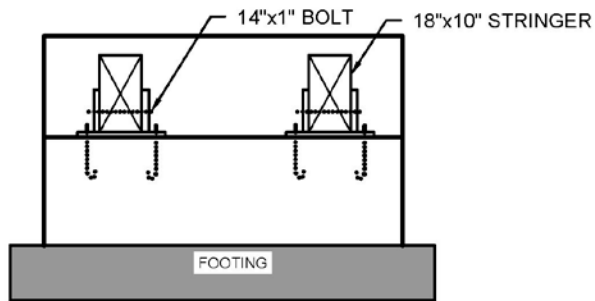
The end form pieces are installed next. Begin by inserting the all thread through the reinforcement steel at the designed locations. The 1/2-inch all thread is cut to a length that extends beyond the form boards approximately 2 inches on each end. Next, lay one form board in place so that the 3/4-inch plywood strips are outside of the front and back form boards. (See Figure 16.28) When the end form board is flush against the tops and ends of the front and back forms, push the pieces of all thread through the pre-drilled holes. Once through the holes, slip a bridge washer over the ends of the all thread and install a 1/2-inch nut onto each piece of all thread. Tighten the nuts down until approximately 3/4-inch of the all thread extends past the nuts. Repeat this process on the opposite end of the form. Then, tighten both nuts down until the end form boards are snug against the front and back form boards.

Now that the form boards are assembled, they need to be leveled and squared. Re-install the batter board string line. Make sure the front of the form board is flush against the string line. Once it is flush, use a straight board and a 4-foot carpenter's level to check the top of the form and see if it is level side to side and front to back. This measurement can also be performed with an auto level and a stadia rod. The height of the beam seat should also be checked to ensure that it is correct. If the layout, fabrication, and assembly of the form boards were performed properly, the abutment form should be very close to square and level, and at the correct elevation. Minor adjustments to the form can be made by loosening the snap tie brackets and all thread nuts and shifting the form boards as necessary. Once the form is square to the string line, level, and at the correct elevation, all the snap tie brackets and all thread bolts should be tightened securely.

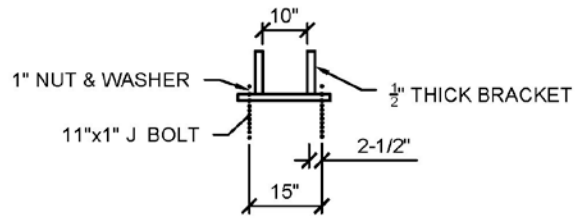
The J bolts that attach the bridge stringer brackets to the beam seat are installed next. (See Figure 16.29.) These bolts need to be placed into the concrete pour

so that the “J” end of the bolt is firmly imbedded into the concrete and the threaded end is projecting far enough above the concrete beam seat to extend through the stringer bracket, wrought iron washer, and nut. The bolts must also be set so they are at the correct location for anchoring the bridge stringer brackets. This task is accomplished by securing the J bolts to a 2- x 4-inch board that is 85 1/2 inches long, and nailing the board to the tops of the end form boards. To layout the J bolt placement on the 2- x 4-inch board, find the center of the board by measuring its length and dividing it in half (i.e., $85 \frac{1}{2} \text{ in.} \div 2 = 42 \frac{3}{4} \text{ in.}$). Lay the board flat, measure the calculated distance (42 3/4 inches) from one end of the board toward the center, and scribe a pencil line across the board. From the center line just scribed, measure half the distance of the outside to outside measurement of the bridge stringers ($60 \text{ in.} \div 2 = 30 \text{ in.}$) toward the end of the board and scribe a pencil line. Repeat this measurement and scribe on the opposite side of the center line. (See Figure 16.29.) Using the dimensions of the beam seat brackets in Figure 16.29, the centers of the bolt holes are 2 1/2 inches out from the inside of the bracket’s flange or from the outside of the bridge stringer line just scribed. Measure 2 1/2 inches outward from the line marking the outside of the stringer and scribe a line. (See Figure 16.29.) This line represents the center of the outside J bolt. From this center line, measure 15 inches (distance between the centers of the two bolt holes) toward the center of the board and scribe a line. This line represents the center line of the inside J bolt. At each of these scribed lines, measure from the top of the 2- x 4-inch board down half the width of the board (1 3/4 inches) and scribe two marks 1 inch apart on opposite sides of the line marking the centers of the bolt holes. Then scribe a line connecting these two marks. This line will be perpendicular to the lines marking the centers of the bolt holes. The intersection of these two lines is the center of the 1-inch J bolt hole. (See Figure 16.29.) Repeat this layout process on the other beam seat.

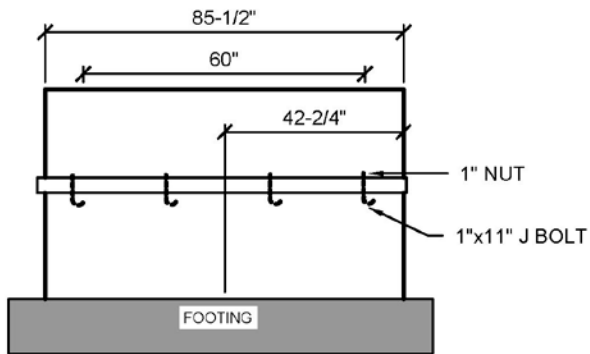
Once the layout is completed, drill the four 1-inch holes in the 2- x 4-inch board. Place the board so the bottom side is up. Then take one of the 1-inch nuts, center it over one of the holes, and trace a line around the nut with a pencil. Use a wood chisel to remove the outline of the nut around the 1-inch drill hole. The depth of the wood removal should be equal to the thickness of the nut. Repeat this process on the remaining 3 holes. Thread a bolt on each of the 1-inch nuts approximately 1 1/2 inches down the thread. Insert the threaded end of the J bolts through the 2- x 4-inch board so that threaded nut slips into the area where wood was removed. Then, place a washer and thread a 1-inch nut on the end of the bolt projecting through the other side of the board. Use a socket or an open end wrench to tighten the end nut. The nut seated inside the board should not turn until the top nut is tight against the board. The J bolt should now be plumb and tightly secured to the board. Repeat this process on the other three bolts. Once completed, coat the bottom of the 2-inch x 4-inch board with form oil.



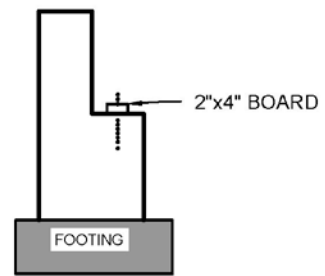
STRINGER ATTACHMENT TO BEAM SEATS
END VIEW



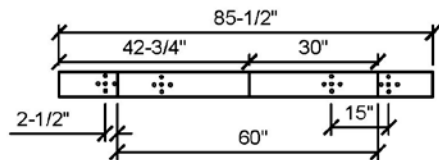
STRINGER BRACKET DETAIL
END VIEW



STRINGER BRACKET J BOLT LAYOUT
FRONT VIEW



STRINGER BRACKET J BOLT LAYOUT
END VIEW



J BOLT 2"x4" BOARD LAYOUT
OVERHEAD VIEW

Figure 16.29 - J Bolt Plan



J BOLT PLAN
CALIFORNIA STATE PARKS

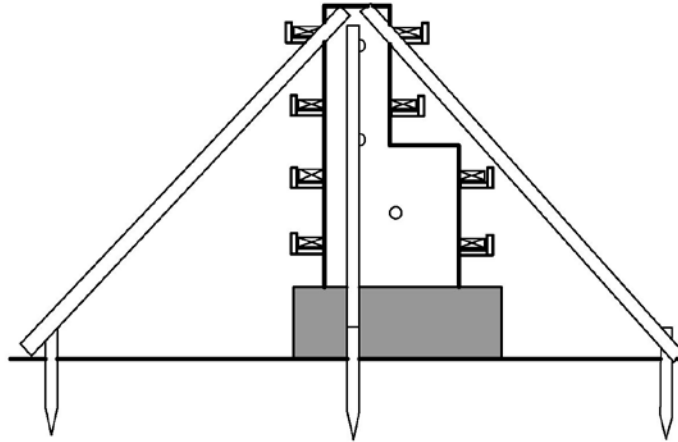
NOT TO SCALE

Next, locate and scribe the center line on top of the beam seat form using the same methods previously described. From that center line, measure half the width of the 4-inch side of the 2- x 4-inch board and scribe a line on top of the form board. Repeat this process on the other side of the line. These two lines can now be used as guides to place the 2- x 4-inch board so that it is centered on the beam seat. Repeat this process on the other beam seat form. Once both forms are marked, set the board on the beam seat forms and drill pilot holes through the 2- x 4-inch board where it will be nailed with 16d duplex nails to the form boards. Note the 2- x 4-inch board is not installed at this time; it will be attached to the forms during the concrete pour.

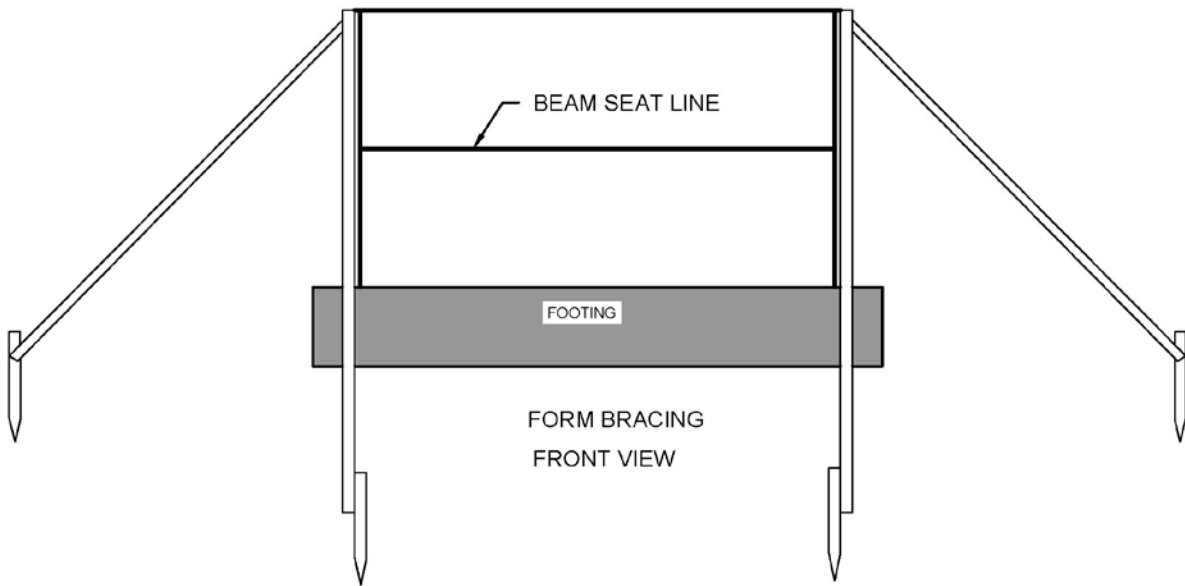
Another method of anchoring the stringer bracket is to install concrete wedge anchors in the beam seat after the concrete has been poured and cured. This method is simpler than installing bolts but the anchors are not as strong. The layout for the anchor locations is performed in a similar fashion as the J bolts but on top of the concrete beam seat. As with the J bolt installation, it is critical that the installation of the rebar and snap ties not interfere with the installation of the wedge anchors. Once the locations for the anchor holes have been marked on the beam seat, use a drill with a 1-inch diameter concrete bit to drill the holes for the anchors. Blow out the concrete dust in the holes and insert 1- x 9-inch concrete wedge anchors. A two-part epoxy glue can also be poured into the drill holes before the bolts are installed to provide additional holding strength to the anchors.

The advantage of using snap ties and all thread is that once the forms are assembled they are extremely strong and not subject to deformities and blow outs. However, they still need to be braced so they do not shift forward or backward once they are filled with concrete. Movement could jeopardize the structural integrity of the abutment and compromise its layout. Bracing is relatively simple to install. Lay a 2- x 4-inch board so that the top of the board is against the end of the abutment form at the top center. The bottom of the board is laid at an approximately 45 degree angle from the top of the abutment form to the ground. The board should also be laid perpendicular to the front of the abutment. Wooden or metal form stakes are then driven securely into the ground next to the board. The brace board is attached to the abutment form and stakes by driving 16d duplex nails through the board and into the form boards or stakes. Pilot holes for the nails should be drilled into the brace boards to reduce the impact to the abutment forms. Repeat this process so each corner of the abutment is braced. (See Figure 16.30.)

Note, once the abutments are laid out, it is often easier to fabricate all the form boards at the shop and assemble them at the bridge site. Having the use of equipment such as power tools and layout tables improves the quality and efficiency of fabricating forms. Fabricating the form boards at the shop also eliminates any conflicts there might be with project noise restrictions and the individual form boards are easy to pack out the trail.



FORM BRACING
END VIEW



FORM BRACING
FRONT VIEW

Figure 16.30 - Form Bracing



FORM BRACING
CALIFORNIA STATE PARKS

NOT TO SCALE

16.7.3.6. Pouring the Stem Wall

Prior to pouring the stem wall concrete on top of the footing, the footing concrete needs to be cleaned of all dirt and oil. A concrete bonding adhesive can also be applied to the footing to facilitate a good bond between the footing and the stem wall. The preparation and pouring of concrete for the stem wall is generally the same as employed in pouring the footing but, the stem wall pour is more difficult because it is often larger in volume and subsequently more difficult to place (working around the forms, snap ties, and steel reinforcement rods). The concrete must be placed and agitated before it begins to set up.

Initially the concrete is poured through the beam seat opening. To provide better access to this area, do not install the 2- x 4-inch board used to hold the J bolts yet. Once the concrete is poured to within 8 inches of the top of the beam seat, the 2- x 4-inch board can be installed. The concrete is then poured around the board until it is level with the top of the beam seat forms and the bottom of the 2- x 4-inch board. The concrete poured in this last 8 inches should be a little stiffer (less water) than the concrete used for the rest of the structure because once the concrete reaches the top of beam seat forms it must be poured into the form through the top of the soil dam opening. If the concrete in the lower portion of the abutment is less dense, the weight of the new concrete will cause it to spill out of the beam seat opening. The first several inches of concrete poured through the soil dam opening should also be of a stiffer mix. It may also be necessary to slow down mixing and pouring concrete during this step to allow the concrete to set-up a little. During this stage of the pour, the use of the vibrator must be carefully managed. Too much agitation can cause the concrete to become more fluid and spill out of the beam seat opening.

Once the concrete in the beam seat opening is firm enough that it will not be forced out of the form, the pour can continue until it reaches the top of the soil dam form. Strike off the excess concrete by working a board back and forth across the top of the soil dam form. During this step, monitor the concrete in the beam seat. Once the concrete has set-up enough so that the J bolts are stable, remove the nuts on top of the bolts and take off the 2- x 4-inch board lying across the beam seat form. Use a wire brush to carefully clean the exposed threads on the J bolts. When the concrete has set-up enough to work the surface, use a trowel to finish off the top of the beam seat and soil dam. Run an edger around the forms to provide a finished edge and facilitate the removal of the form boards.

Note, if the footing and stem wall were poured at the same time, the transition from the footing to the stem wall should be the same as the transition from the beam seat to the soil dam.

Mixing and pouring concrete in the field requires a well-organized and efficient crew because there are many tasks that must be performed simultaneously. Mixing concrete in wheelbarrows must be staggered to ensure that there is a steady and timely flow of concrete to the forms. The production of mixed

concrete must be synchronized with the pouring and working of the concrete in the forms. A breakdown or other problem that interrupts the flow of concrete to the forms can lead to an inconsistent concrete matrix, uneven curing, and a weakened abutment.

After the concrete has cured a minimum of seven days, the forms can be removed. First remove the form braces. Next, remove the nuts and bridge washers at the ends of the all thread using a wrench. Carefully loosen the side forms from the concrete and slide them over the 2 inches of all thread projecting through the form. Then, remove the snap ties by using a 1/2-inch six point socket and a ratchet. Place the socket over the head of the snap tie and turn the ratchet clockwise. Within a quarter to half a turn, the snap tie will break off inside the concrete. Remove all the snap tie brackets and their associated waler boards. Then carefully loosen and remove the front and back form boards.

Using a wrench, remove the 1-inch nuts at the base of the J bolts. These nuts should be elevated above the beam seats. They could not be removed until the concrete was cured enough to prevent the J bolts from loosening. Use a hacksaw, oxy-acetylene torch, or angle grinder to cut the 1/2-inch all thread flush with the concrete. If the concrete abutment is not to be faced with a rock mortar facade, chisel or grind off all extruded concrete. Fill the voids left by the snap tie cones with mortar. Clean-up and remove all excess concrete, forms, braces, stakes, and trash.

16.8. Wooden Trestle Construction

Being a load-bearing structure, a trestle requires a strong and stable foundation. Unless the underlying soil is very firm and stable, a concrete footing usually serves as the foundation. The slab is formed and poured on level and compacted mineral soil or rock. It is recommended that the concrete slab be a minimum of 1 foot longer than the mudsill, which varies depending on the height of the trestle. It should be a minimum of 2 feet wide for a single trestle and 4 feet wide for double trestle. The slab should have a minimum thickness (depth) of 1 foot. For additional structural strength, the slab should be reinforced with 5/8-inch rebar. Galvanized 1-inch J bolts are inset into the concrete slab. These bolts anchor the galvanized or stainless steel metal brackets used to secure the mudsill to the concrete slab. The procedures for forming and pouring the footing are identical to those used in concrete footings described previously.

The trestle should be constructed of con heart grade redwood, Alaskan yellow cedar, or pressure treated Douglas fir. The trestle consists of three components: the mudsill, the columns, and the trestle sill. If a single free span of the bridge exceeds 32 feet, a double trestle should be used to distribute the additional load. (See Figures 16.31 and 16.32.)

OUTSIDE SUPPORT
COLUMNS DIRECTLY
UNDER BRIDGE
STRINGERS

STRINGER

STRINGER ATTACHED W/
GALV. STEEL BRACKET
AND THROUGH BOLTED

12"X14" TRESTLE
SILL

4"X8" CROSS
BRACING

8"X12" OUTSIDE
SUPPORT COLUMNS

8"X14" CENTER
SUPPORT COLUMN

14"X14"
MUDSILL

2" AIR
GAP

min 8"

8°

min 8"

ATTACHED WITH
STEEL BRACKETS
IF CONC. FOUNDATION

ATTACH WITH
 $\frac{5}{8}$ " REBAR EVERY 3'
IF SOIL
FOUNDATION

COLUMNS ATTACHED
WITH STEEL BRACKETS
AND THROUGH
BOLTED

$\frac{5}{8}$ " THROUGH BOLT W/
MALLEABLE IRON
WASHERS

Figure 16.31 - Single Trestle Detail



SINGLE TRESTLE DETAIL

CALIFORNIA STATE PARKS

NOT TO SCALE

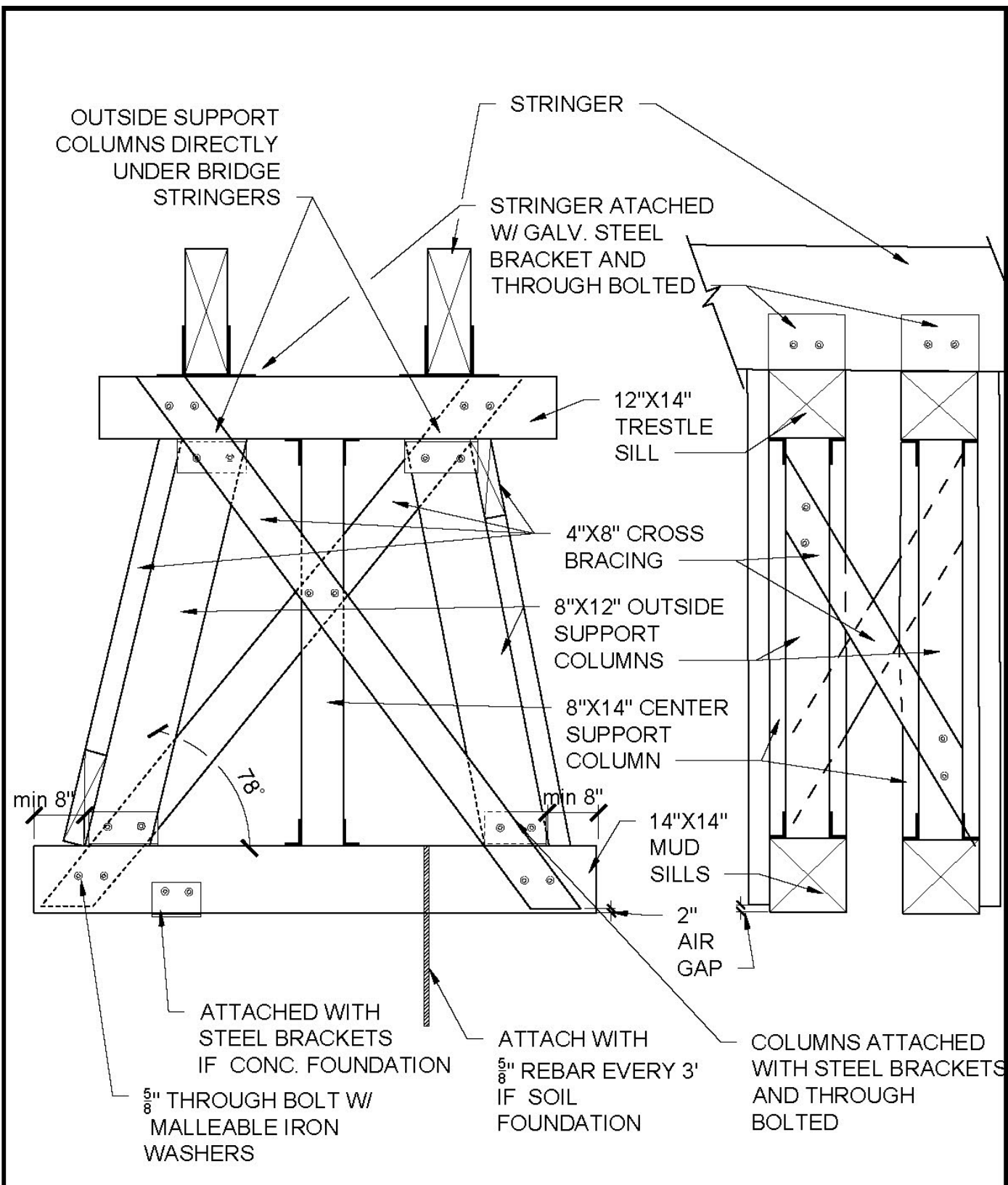


Figure 16.32 - Double Trestle Detail

The outside support columns should connect to the mudsill at a 78 degree angle. The top, outside edge of each column should line up with the outside edge of the stringers. The bottom, outside edge of the columns should be a minimum of 8 inches from the end of the mudsill.

The minimum end dimensions of the mudsill should be 14 x 14 inches. The length of the mudsill will vary depending on the height of the trestle but should be a minimum of 8 feet to provide adequate stability and load-bearing surface area. For every 1 foot increase in the height of the trestle (measured from the top of the mudsill to the bottom of the trestle sill), the distance between the outside support columns needs to be increased by 6 inches (e.g., move each column 3 inches outward) to maintain the 78 degree angle of the columns to the mudsill.

For example, if a trestle has a height of 3 feet between the mudsill and the trestle sill, the distance between the outside support columns should be increased by 18 inches (3 feet x 6 inches per foot). If the bridge stringers are 5 feet (60 inches) apart, the outside support columns should be 60 inches apart at the trestle sill (distance between the stringers) and 78 inches apart at the mudsill (18 inches + 60 inches = 78 inches) to achieve the 78 degree angle between the columns and the mudsill. Adding the requisite 8-inch setback from the ends of the mudsill, the total length of the mudsill should be 94 inches [78 inches between columns + 16 (8 inches at each end) = 94 inches].

Similarly, a bridge with stringers 5 feet apart and a trestle 8 feet high between the mudsill and the trestle sill would have outside support columns 60 inches apart at the trestle sill (distance between the stringers' outside to outside measurement) and 108 inches apart at the mudsill (8 feet x 6 inches per foot = 48 inches; 48 inches + 60 inches = 108 inches). Adding the 8-inch setback from the ends of the mudsill, the mudsill length would be 124 inches [108 inches between columns + 16 (8 inches at each end) = 124 inches].

The outside support columns' end dimensions should be a minimum of 8 x 12 inches. If the height of the trestle (measured from the top of the mudsill to the bottom of the trestle sill) is greater than 3 feet, a third 8 x 14-inch center support column is placed in the middle. To attach the columns to the mudsill, metal brackets are bolted to the mudsill with 5/8- x 10-inch galvanized lag screws and the columns are through bolted to the brackets with 5/8- x 10-inch galvanized hex headed bolts. The outside support columns attach to the trestle sill directly beneath the stringers and extend downward at an angle of 12 degrees outward from vertical, giving the structure an inverted "V" shape. This angle lends stability to the structure. (See Figures 16.31 and 16.32.)

The trestle sill should have minimum end dimensions of 12 x 14 inches with a length not exceeding the length of the mudsill. To attach the columns to the trestle sill, metal brackets are bolted to the trestle sill with 5/8- x 10-inch galvanized hex headed bolts and the columns are through bolted to the brackets with 5/8- x 10-inch galvanized hex headed bolts.

The trestle sill must be installed square and level to the trestle sill(s) supporting the opposite end of the bridge stringers. The bridge stringers should be attached to the trestle sill via galvanized or stainless steel brackets and through-bolted. If the trestle is joining two spans with stringers of different dimensions, fabricated metal supports may be placed beneath the smaller stringers to bring them level to the top of the larger stringers. The trestle sills should be centered over the mudsill with respect to both length and width. (See Figures 16.31 and 16.32.)

Cross bracing with a minimum dimension of 4 x 8 inches should be attached to both sides of the trestle to prevent rocking. The cross braces should extend diagonally from the top of the trestle sill to the bottom of the opposite mudsill. The cross bracing is fastened to the mudsill and trestle sill with 5/8- x 20-inch galvanized hex headed bolts. Cross braces are installed so they join the mudsills and trestle sills at approximately the same location on the outermost support columns. If both sides are cross braced, the cross braces will run in opposite directions. Where possible, cross braces should be fastened to the center support columns as well. (See Figures 16.31 and 16.32.)

When two trestles are used, cross bracing should be installed to join them. In this instance, cross bracing is fastened to the top of the outside support column of one trestle and to the bottom of the outside support column on the other trestle. Both sets of outside support columns should be cross braced, with braces running in opposite directions. (See Figure 16.32.)

16.9. Abutment Sill Construction

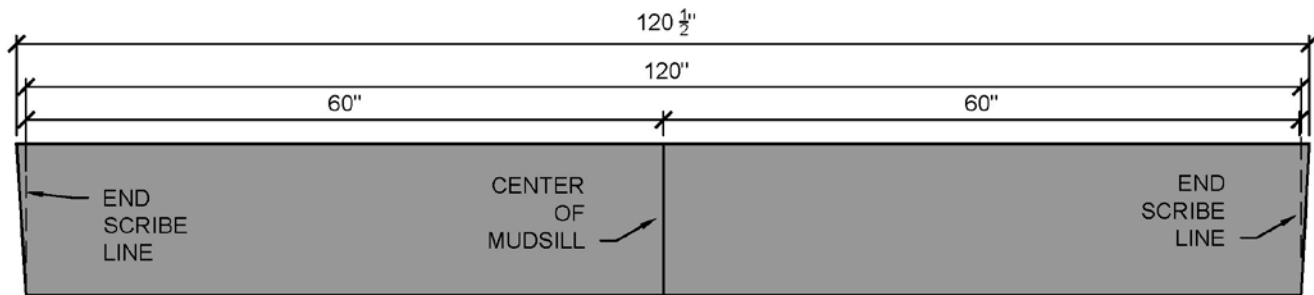
16.9.1. Wooden and Plastic Wood Sills

Wooden and plastic mudsills are usually purchased pre-cut to the prescribed dimensions. Although redwood, cedar, and plastic wood can be cut to the desired lengths, pressure treated wood should be purchased at the prescribed lengths because cutting pressure treated wood compromises the preservative treatment. Since these mudsills are commonly found in large dimensions, transporting them to the bridge site can be difficult. Depending on the trail width and tread condition, these mudsills can be transported by crews using timber carriers, trail cart, toter, or stringer dolly. An ATV or small trail dozer with a trailer attachment may also be used if the trail width is adequate. It may also be possible to use a skyline to transport the mudsills. A helicopter is an option, especially if the bridge superstructure is already being transported that way. In remote settings, wooden mudsills can be manufactured from nearby rot-resistant wood, such as redwood or cedar. These mudsills are fabricated from downed trees that are solid and structurally sound. The logs are bucked to the required length and then sawn or split to the correct dimension.

It is likely that the wooden or plastic wood mudsills are not identical lengths. Factory cuts or those performed by the crew are often off by as much as a 1/2 inch. Check the length of the mudsills to ensure they are the same. Use a framing square

to check that the ends of the mudsills have been cut at a right angle. If they are not square, they can be re-cut. However, for layout purposes, it might be simpler to measure and identify uniform lengths. Start by measuring the length of all the mudsills to identify the shortest one. These measurements should be performed on the shortest side of the mudsill, as the length of each side of the mudsill will differ if the ends are not cut square. In the example in Figure 16.33, the short side length is 120 inches. Divide this length in two ($120 \text{ in} \div 2 = 60 \text{ in.}$). Then, measure that distance from the end of one of the short sides towards the center of the mudsill to find the center of the mudsill. Mark that location and use a carpenter's square to scribe a pencil line from top to bottom. Then from the center line, measure out toward the ends of the mudsill that same distance (60") to locate the end of mudsill lines. Mark those locations and use a framing square to scribe a pencil line from top to bottom. These lines are at a right angle to the mudsill's length. Then, following the layout process for locating the center line as described above, scribe the center lines for the remaining mudsills. Once the center lines have been scribed, use the short mudsill measurement of 60 inches to locate and scribe the end lines on all the remaining mudsills. The end scribe lines will be of equal measurement for all mudsills and can now be used for future distance and squaring tasks. The center line will also be used in future layout tasks. (See Figure 16.33.)

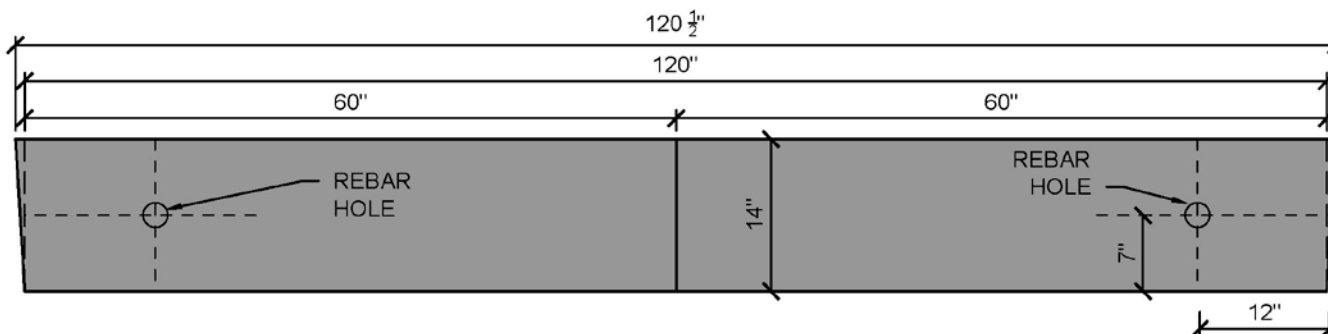
Before placing the mudsills, drill two 5/8-inch diameter holes through the center of each mudsill, approximately 1 foot from each end. Make sure these holes will not interfere with the placement of the beam seat brackets. Once they are leveled and squared, the holes will be used to pin the mudsill to the abutment with 5/8-inch x 3-foot pieces of rebar. When drilling these holes, use wooden blocks to elevate the mudsills off the ground to keep the drill bit from contacting the soil/rock beneath the mudsill. It also reduces the disturbance to the abutment surface. (See Figure 16.33.)



1. DETERMINE THE SHORTEST MUDSILL. MEASURE THE SHORTEST SIDE OF THIS MUDSILL. IN THIS EXAMPLE (120"). DIVIDE THIS LENGTH IN HALF (120"/2= 60").

2. MEASURE 60" FROM ONE OF THE SHORT SIDE ENDS TOWARDS THE CENTER OF THE MUDSILL. MARK THIS LOCATION AND USE A CARPENTER'S SQUARE TO SCRIBE A PENCIL LINE FROM TOP TO BOTTOM TO IDENTIFY THE CENTER OF THE MUDSILL.

3. MEASURE OUT 60" FROM THE CENTER OF THE MUDSILL TO DETERMINE THE END OF MUDSILL LINES. MARK THESE LOCATIONS AND USE A CARPENTER'S SQUARE TO SCRIBE A PENCIL LINE FROM TOP TO BOTTOM.



4. DETERMINE MUDSILL CENTERS FOR ALL REMAINING MUDSILLS AND MEASURE OUT 60" FROM THESE CENTER LINES TO LOCATE AND SCRIBE MUDSILL END LINES. THESE END SCRIBE LINES WILL BE OF EQUAL MEASUREMENT FOR ALL MUDSILLS AND CAN BE USED FOR FUTURE DISTANCE AND SQUARING TASKS. THE CENTER LINE WILL ALSO BE USED IN FUTURE LAYOUT TASKS.

5. MEASURE 12" IN FROM THE END LINES AND SCRIBE LINES FROM TOP TO BOTTOM. THESE LINES REPRESENT THE CENTERLINE DISTANCE IN FROM THE END LINES TO WHERE THE REBAR HOLE WILL BE LOCATED.

6. MEASURE THE WIDTH (14") OF THE MUDSILL & DIVIDE IT IN HALF (7"). MEASURE THAT DISTANCE FROM THE BOTTOM OF THE MUDSILL AND SCRIBE A LINE ACCROSS THE CENTER OF THE MUDSILL TO IDENTIFY THE SIDE TO SIDE CENTER OF THE REBAR HOLE. DRILL $\frac{5}{8}$ " DIA. HOLES THROUGH THE MUDSILL AT THE INTERSECTION OF THE CENTERLINES.



$\frac{5}{8}$ " x 3' REBAR

7. ONCE THE MUDSILLS ARE LEVEL, THE CORRECT DISTANCE APART AND SQUARED TO EACH OTHER DRIVE $\frac{5}{8}$ " x 3' PIECES OF REBAR THROUGH THE TWO PRE DRILLED HOLES IN THE MUDSILLS.

Figure 16.33 – Laying Out and Anchoring the Mudsills



LAYING OUT AND ANCHORING THE MUDSILLS

CALIFORNIA STATE PARKS

NOT TO SCALE

Once on-site, the mudsills are commonly placed by a crew with timber carriers. If a steep ravine or deeply incised channel must be crossed, a high lead or skyline can be used to transport the mudsills from one side of the watercourse to the other. At this point in the construction process, the earthen or soil/rock retention abutments have been constructed, leveled, compacted, and squared. Batter boards and string lines or ledger boards have been installed to identify the exact locations the mudsills are to be placed.

Once the mudsills have been set on the abutment using the string lines or ledger boards as guides, they must be checked for level both individually and to each other. If the layout and abutment construction were performed correctly, the mudsills will require very little adjustment. Using an auto level and a stadia rod, sight the elevations at the center of the mudsills (front and back) and each corner of the mudsills. (See Figure 16.34.) Record these elevations on a simple site plan. Next, check the abutment layout plans to ensure that the top of the mudsills are at the prescribed finished elevation, so that once the bridge is constructed, it will be at the correct elevation.

If the tops of the mudsills are at an elevation that is slightly higher or lower than called for in the layout plans, they need to be adjusted. If elevation adjustments are required, use two cant hooks or peaveys to roll the mudsill backward away from the string lines or ledger boards. If some locations are too high, lower them by excavating to the correct elevation. If they are too low, then elevate those locations by importing aggregate. Aggregate can be salvaged from excavation of the abutments or trail tread. The aggregate must be properly compacted. Avoid using soil for fill since it is difficult to compact in thin layers and over time will settle more than aggregate. Once completed, roll the mudsills forward, line them up with the string lines or ledger boards, and take new elevation readings with the auto level. Repeat until all the mudsills are level individually and to each other, and are at the correct finished elevation.

To ensure that there is equal distance between each mudsill and its corresponding mudsill on the opposite bank, measure the distance from the back of each rear mudsill (if more than one mudsill per side) to the back of each rear mudsill on the opposite abutment. These measurements are taken from the scribed lines at the end of each mudsill. (See Figure 16.35.) Record these measurements on the site plan. Compare these distances against the designed layout. Again, if the batter board lines or ledger boards were installed correctly, these measurements should be the same and the mudsills should be the correct distance apart. If one side of the mudsills is at the correct distance apart and the other side is slightly less, move each mudsill on the short measurement side backwards half the distance between the two measurements. (See Figure 16.36.)

For example, the correct abutment layout measurement is 30 feet between the opposite bank mudsills, but one of the end measurements between the mudsills is 30 feet and the other end measurement is 29 feet 3/4 inches. To correct this

discrepancy, move each mudsill on the short measurement $\frac{1}{8}$ inch back. (See Figure 16.36.) If only one mudsill is moved back to correct the difference, the mudsills will no longer be square to each other. Moving mudsills must be done very carefully. Use a rock bar to gently move the shorter measurement side of the mudsill. While this task is being performed, the opposite end of the mudsill must be held stationary so it will not move forward. Usually having someone brace the front of the mudsill with their foot will suffice. Once the mudsills are the correct distance from each other, drive in two pieces of rebar behind each mudsill approximately 1 foot from the end of the mudsills. This rebar is driven against the back of the mudsill, so that the mudsill cannot move backward. The rebar will help maintain the correct distance when the mudsills are square to each other.

Next, determine if the mudsills are square to each other by measuring diagonally from the back of one rear mudsill to the back of the rear mudsill on the opposite abutment. Measure from the scribed lines previously marked at each end of the mudsills. (See Figure 16.37.) Record the measurement on a site plan. If the mudsills are square to each other, the diagonal measurements will be the same. If they are not, the mudsills are out of square and will need to be corrected.

To correct mudsills that are out of square, subtract the short measurement from the long measurement and divide it in half. To square the mudsills, move one of the two mudsills laterally (parallel to the mudsill and perpendicular to the bridge alignment) by that amount. (See Figure 16.38.) For example, if the long measurement is 36 feet and the short measurement is 35 feet 11 $\frac{3}{4}$ -inches, the difference between the two measurements is $\frac{1}{4}$ inch. Divide $\frac{1}{4}$ inch in half and move one of the mudsills laterally or sideways outward on the short side by that amount (i.e., $\frac{1}{8}$ inch). This correction will effectively lengthen the short measurement $\frac{1}{8}$ inch and shorten the long measurement $\frac{1}{8}$ inch. Use a rock bar to facilitate movement of the mudsill. Slide the mudsill along the rebar to prevent the mudsill from moving forward or backward. Re-measure and repeat this process as necessary. Once the mudsills are square to each other, re-check the distance between and elevations of the mudsills. Sometimes, even a subtle adjustment can alter these measurements. If necessary, correct any discrepancies following the processes previously discussed.

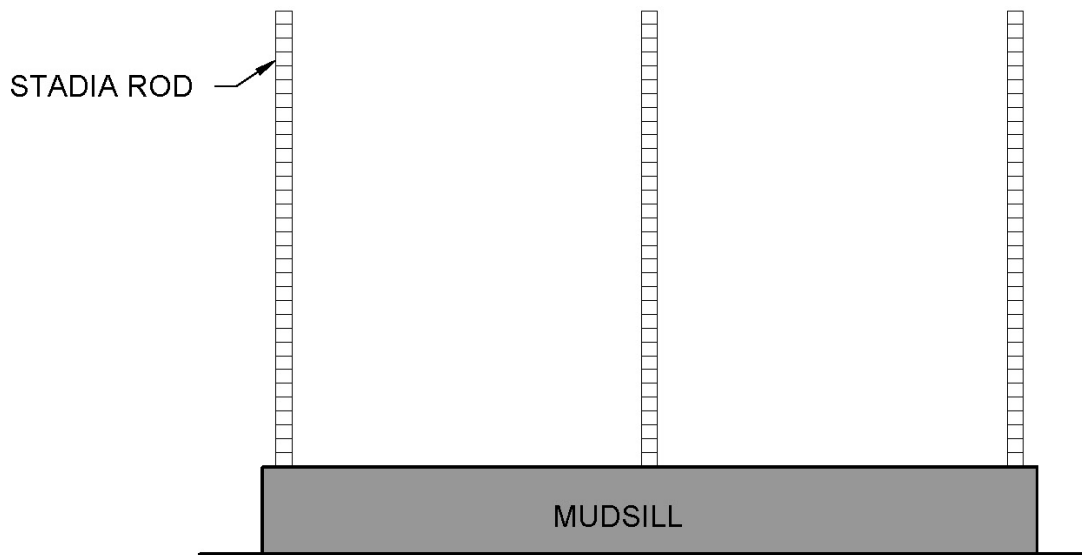
Once the mudsills are at the correct elevation, distance, and squared, carefully pin each to its abutment by driving $\frac{5}{8}$ -inch x 3-foot rebar through the pre-drilled holes in the mudsills. (See Figure 16.33 and Photo 16.29.) Pinning the mudsills prevents them from being inadvertently moved when the bridge stringers are placed and squared.



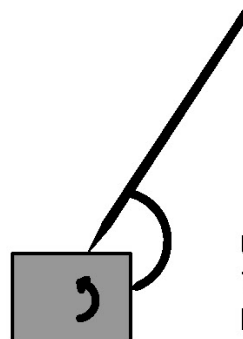
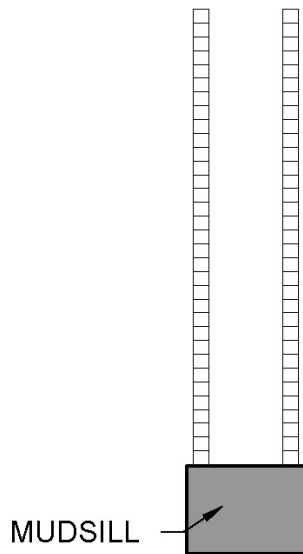
Photo 16.29 - Pinning the Mudsill With Rebar

If additional mudsills are prescribed in front of the two just placed, they can be set-up against the two just installed. Place them so the two outside and one center scribed pencil lines on each mudsill are aligned. If the design calls for spreading the two mudsills apart, square them by using the cross measurement method. Check to ensure that the elevations are the same and correct as necessary. (See Figure 16.39.) Pin the mudsills once they are level to each other.

Installing mudsills is greatly facilitated by utilizing batter boards and string lines or ledger boards. Attempting this process without these aids can be very frustrating and time consuming, and often leads to improperly installed mudsills.



USE AN AUTO LEVEL AND STADIA ROD TO CHECK THE ELEVATION OF THE MUDSILL. SIGHT STATIONS IN THE CENTER OF THE MUDSILL AND ON EACH END. SIGHT THE FRONT AND BACK OF THE MUDSILL AT EACH OF THESE LOCATIONS. THERE ARE SIX STATIONS FOR EACH MUDSILL.



USE TWO PEAVEYS TO ROLL THE MUDSILL BACKWARDS. LEVEL PAD THEN ROLL MUDSILL FORWARDS INTO ITS CORRECT POSITION.

Figure 16.34 - Leveling the Mudsills



LEVELING THE MUDSILLS

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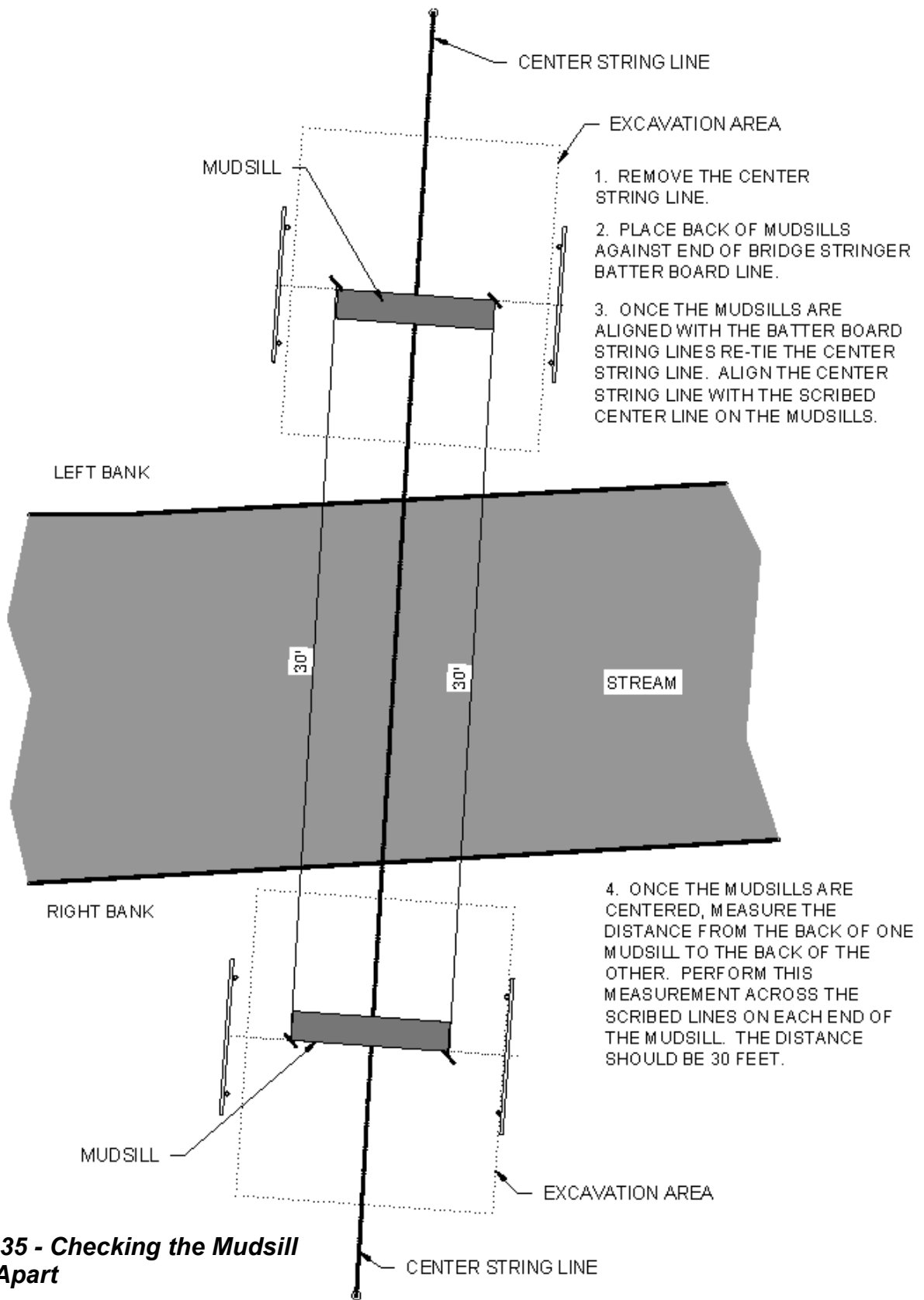


Figure 16.35 - Checking the Mudsill Distance Apart



CHECKING THE MUDSILL DISTANCE APART

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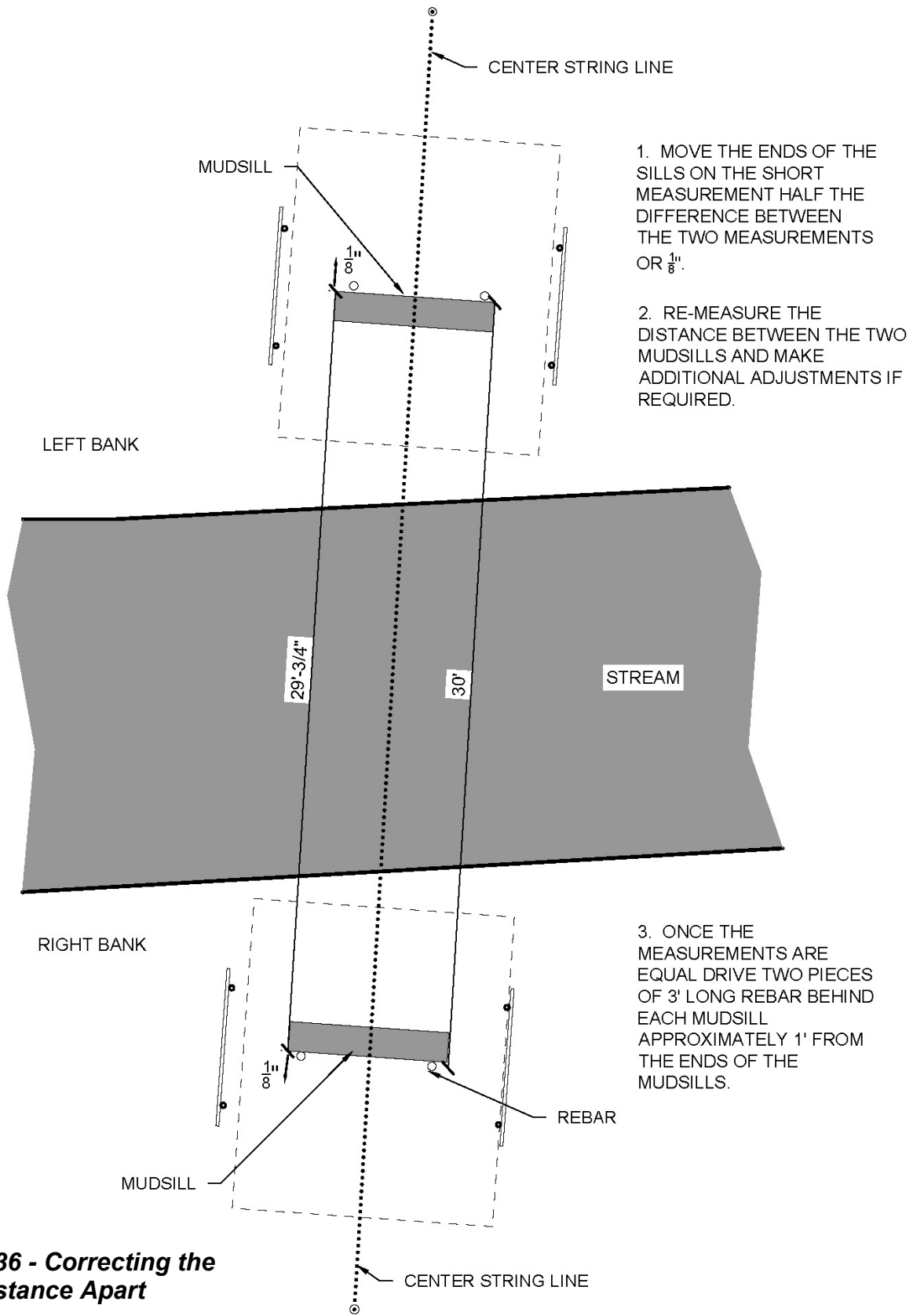


Figure 16.36 - Correcting the Mudsill Distance Apart



CORRECTING THE MUDSILL DISTANCE APART

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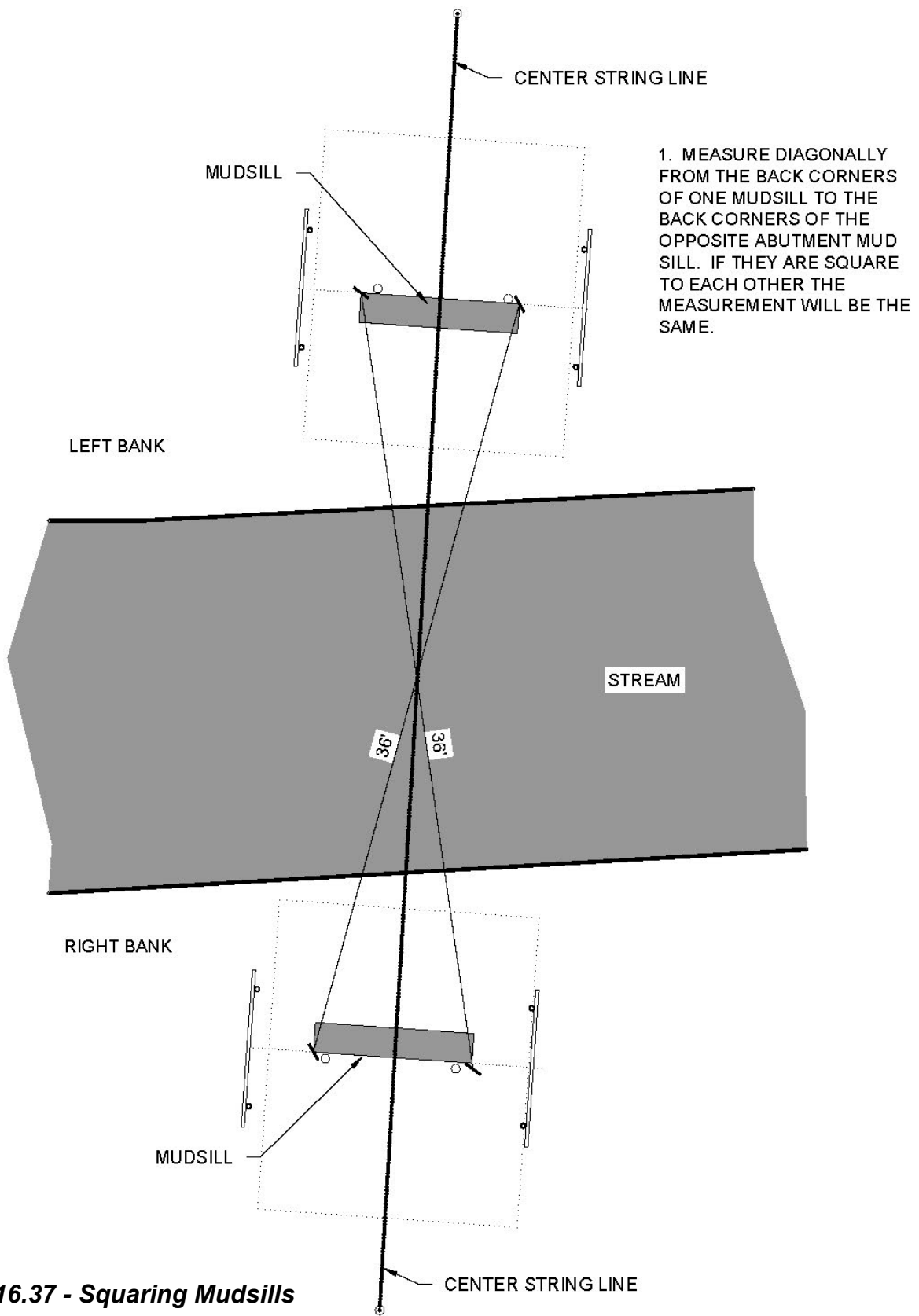


Figure 16.37 - Squaring Mudsills



SQUARING MUDSILLS
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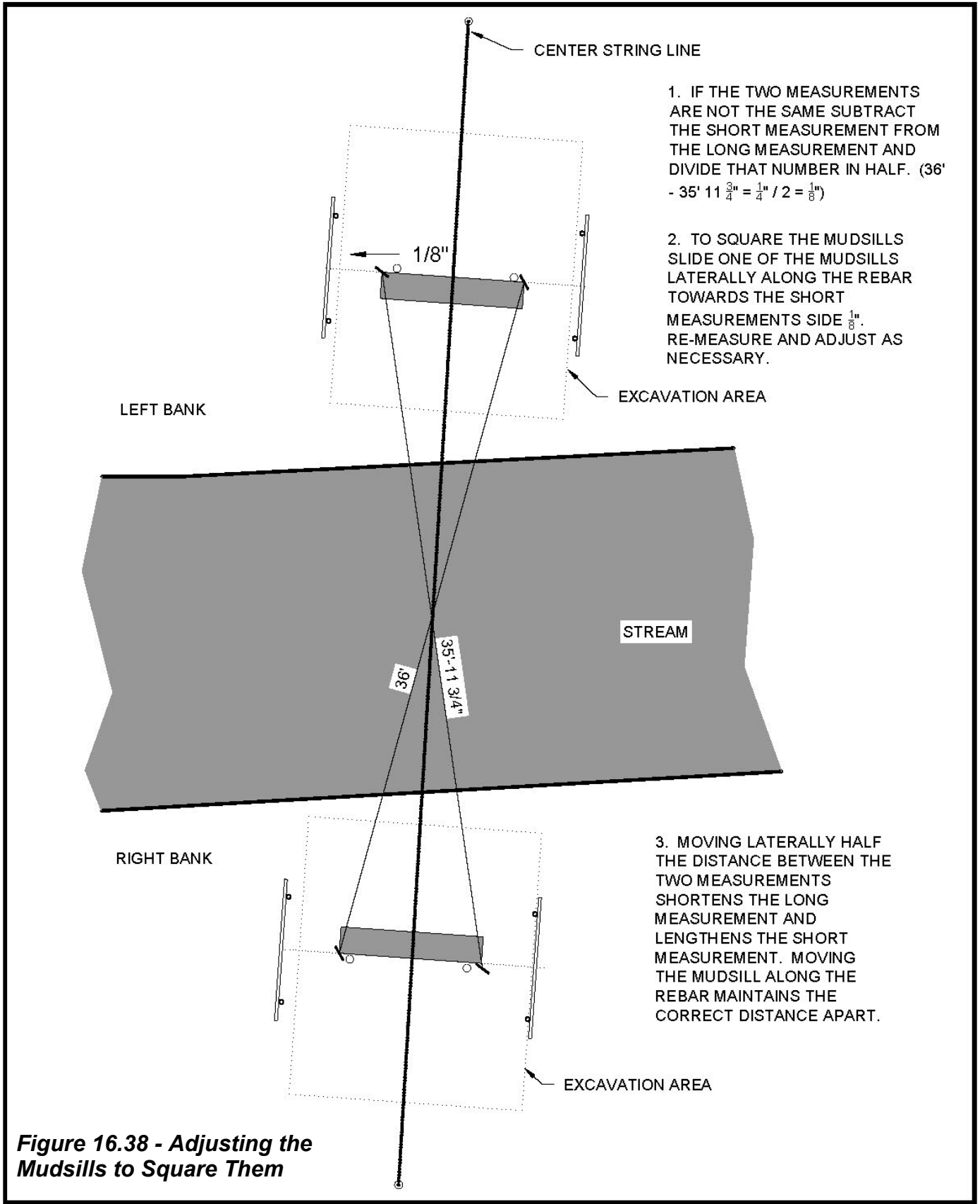


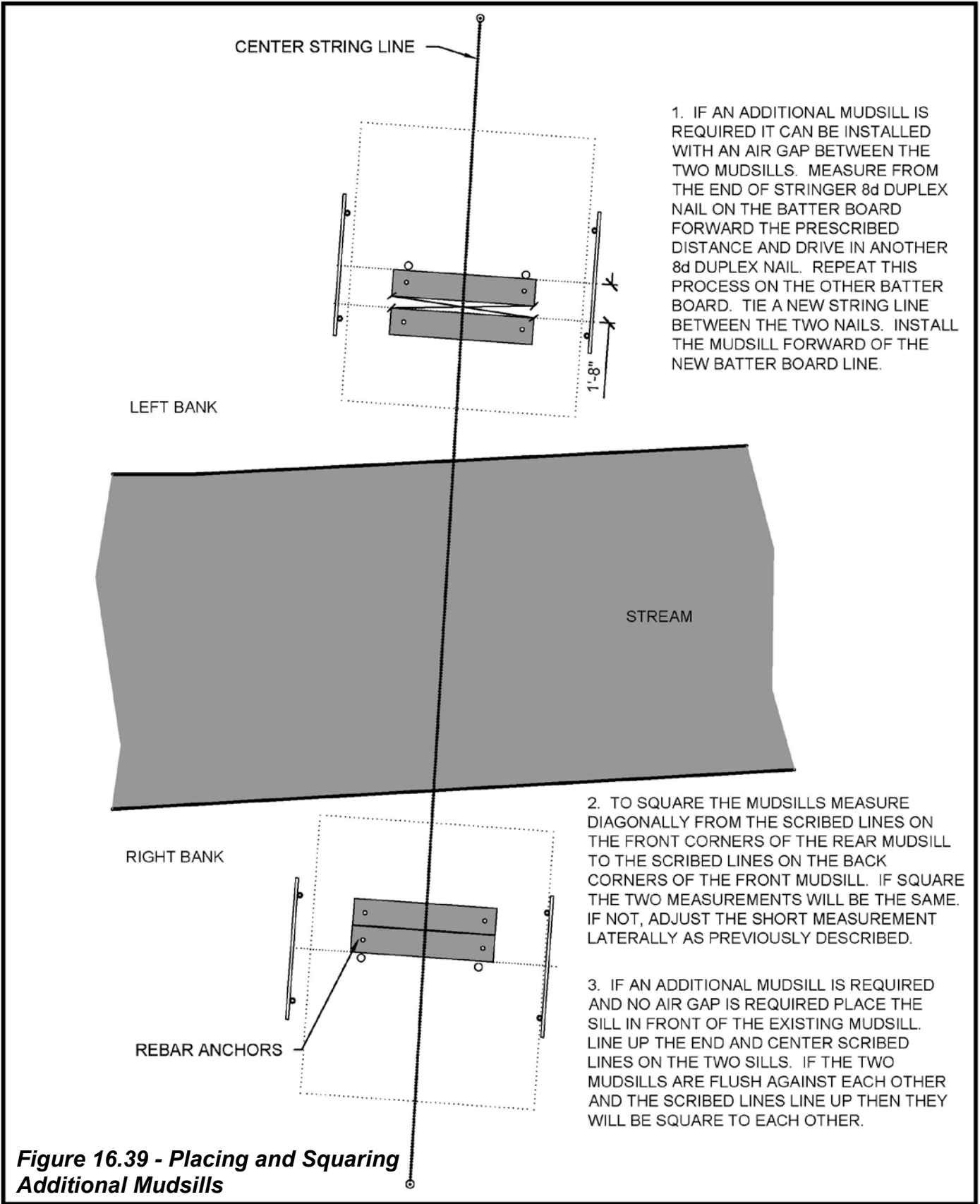
Figure 16.38 - Adjusting the Mudsills to Square Them



ADJUSTING THE MUDSILLS TO SQUARE THEM

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1. IF AN ADDITIONAL MUDSILL IS REQUIRED IT CAN BE INSTALLED WITH AN AIR GAP BETWEEN THE TWO MUDSILLS. MEASURE FROM THE END OF STRINGER 8d DUPLEX NAIL ON THE BATTER BOARD FORWARD THE PRESCRIBED DISTANCE AND DRIVE IN ANOTHER 8d DUPLEX NAIL. REPEAT THIS PROCESS ON THE OTHER BATTER BOARD. TIE A NEW STRING LINE BETWEEN THE TWO NAILS. INSTALL THE MUDSILL FORWARD OF THE NEW BATTER BOARD LINE.

2. TO SQUARE THE MUDSILLS MEASURE DIAGONALLY FROM THE SCRIBED LINES ON THE FRONT CORNERS OF THE REAR MUDSILL TO THE SCRIBED LINES ON THE BACK CORNERS OF THE FRONT MUDSILL. IF SQUARE THE TWO MEASUREMENTS WILL BE THE SAME. IF NOT, ADJUST THE SHORT MEASUREMENT LATERALLY AS PREVIOUSLY DESCRIBED.

3. IF AN ADDITIONAL MUDSILL IS REQUIRED AND NO AIR GAP IS REQUIRED PLACE THE SILL IN FRONT OF THE EXISTING MUDSILL. LINE UP THE END AND CENTER SCRIBED LINES ON THE TWO SILLS. IF THE TWO MUDSILLS ARE FLUSH AGAINST EACH OTHER AND THE SCRIBED LINES LINE UP THEN THEY WILL BE SQUARE TO EACH OTHER.

Figure 16.39 - Placing and Squaring Additional Mudsills



PLACING AND SQUARING ADDITIONAL MUDSILLS

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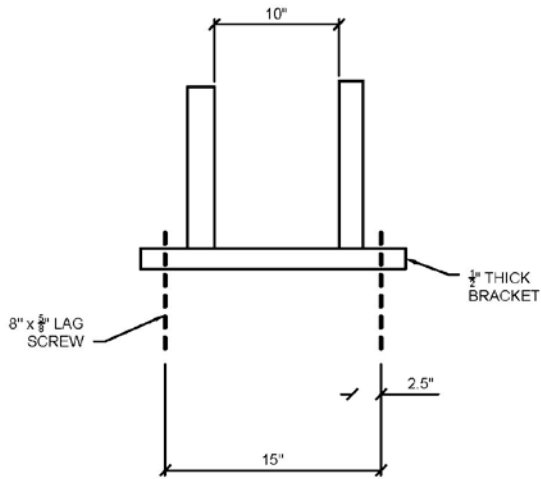
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Once all the mudsills are installed, the beam seat brackets are installed. The brackets secure the bridge stringers to the mudsills. They are commonly made of galvanized or stainless steel. They are attached to the mudsills with lag screws. The bridge stringers are attached to the metal brackets by a bolt that runs through the bracket and stringer.

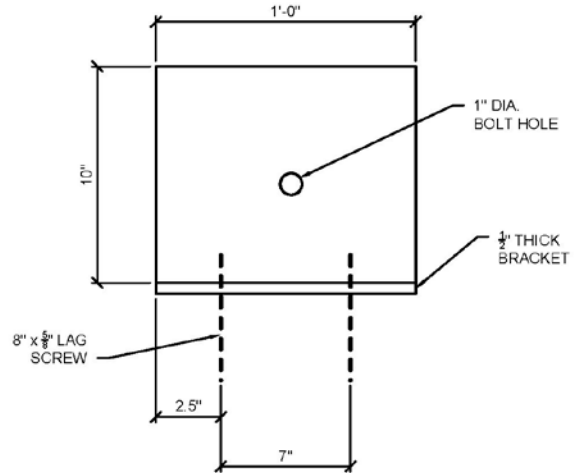
The layout for installing the beam seat brackets is similar to the one used for placing the J bolts on a concrete abutment. (See Figure 16.40.) Begin by measuring outward from the scribed center line of the mudsill by half the outside to outside width of the bridge stringers (e.g., $60 \text{ in} \div 2 = 30 \text{ in}$). At that location, scribe a pencil line across the mudsill from top to bottom. Repeat the measurement and scribe on the opposite side of the center line. Using the dimensions of the bridge stringer brackets (overhead view) shown in Figure 16.40, measure $2 \frac{1}{2}$ inches outward from the outside bridge stringer line and scribe a line to represent the top to bottom center line of the lag screw holes for the beam seat bracket. From that scribed line, measure 15 inches toward the center of the mudsill and scribe a second line. The second line represents the top to bottom center line of the inside lag screw holes for the beam seat bracket. Next, measure in along the two top to bottom center lines $3 \frac{1}{2}$ inches from the front and back edges of the mudsill and mark that distance with a pencil. Scribe a side to side line along the mudsill to connect these $3 \frac{1}{2}$ -inch marks. The intersection of the top to bottom and side to side line is the center of the beam seat bracket lag screw holes. (See Figure 16.40.) Repeat this layout process for the bridge stringer bracket on the other side of the mudsill and the brackets for the mudsill on the opposite abutment.

Once the layout for the beam seat brackets is completed, drill a pilot hole at the center of each bracket hole just scribed. The pilot hole should be approximately $\frac{1}{8}$ inch less than the diameter and 1 inch less than the length of the lag screw used to fasten the bracket to the beam seat. Place the beam seat brackets on the mudsills so that the holes are centered on the pilot holes. Slip wrought iron washers onto the lag screws and screw down the lag screws with a socket and ratchet or an impact driver (if there is a power source). If the mudsill wood is hard, apply hand soap (in a can) to the lag screws to lubricate them, expedite screwing them into the mudsill, and prevent shearing the lag screws. Re-check the layout measurements for the brackets before fully seating the lag screws and then screw them down tightly. If there is more than one mudsill per side, a second set of beam seat brackets (four per side if there are two mudsills per abutment) are needed. Be sure to order the additional beam seat brackets when purchasing the bridge package or when purchasing the hardware, if purchase separately. Repeat the previous process to install the beam seat brackets on the additional mudsills.

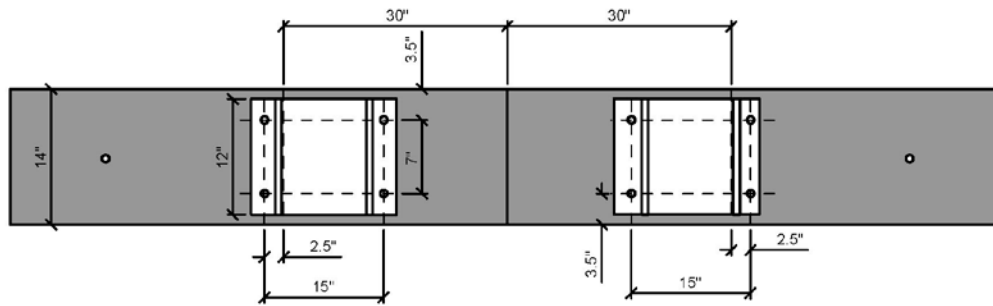
Note, when installing the beam seat brackets on wooden mudsills, avoid notching into the mudsill to keep the bracket flush with the top of the mudsill. Notched pockets can trap water and debris, which increase the risk of rot in the mudsills.



STRINGER BRACKET DETAIL
END VIEW



STRINGER BRACKET DETAIL
SIDE VIEW



STRINGER BRACKET LAYOUT DETAIL
OVERHEAD VIEW

1. MEASURE 30" OUT, EITHER SIDE, FROM THE CENTER OF THE MUDSILL AND SCRIBE LINES FROM TOP TO BOTTOM ACROSS THE MUDSILL. THESE LINES REPRESENT THE OUTSIDE EDGE OF THE BRIDGE STRINGERS

2. MEASURE 2.5" OUT FROM THE OUTSIDE EDGE OF STRINGER LINES AND SCRIBE LINES FROM TOP TO BOTTOM ACROSS THE MUDSILL. THESE LINES REPRESENT THE TOP TO BOTTOM CENTER OF THE OUTSIDE LAG SCREW HOLES. THEN MEASURE 15" INWARD FROM THOSE LINES AND SCRIBE LINES FROM TOP TO BOTTOM ACROSS THE MUDSILL. THESE LINES REPRESENT THE TOP TO BOTTOM CENTER OF THE INSIDE LAG SCREW HOLES.

3. MEASURE 3.5" IN FROM THE BOTTOM EDGE OF THE MUDSILLS AND SCRIBE LINES SIDE TO SIDE ON THE MUDSILLS SO THEY INTERSECT WITH THE TOP TO BOTTOM LAG SCREW HOLE LINES. THESE LINES REPRESENT THE SIDE TO SIDE CENTER OF THE LAG SCREW HOLES. THE INTERSECTION OF THE TOP TO BOTTOM AND SIDE TO SIDE LINES REPRESENT THE CENTER OF THE LAG SCREW HOLES.

Figure 16.40 - Mudsill Beam Seat Bracket Layout



MUDSILL BEAM SEAT BRACKET LAYOUT

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16.9.2. Concrete Sills

A concrete sill can be a simple, free-standing pour or it can be a concrete sill poured on top of existing bed rock.

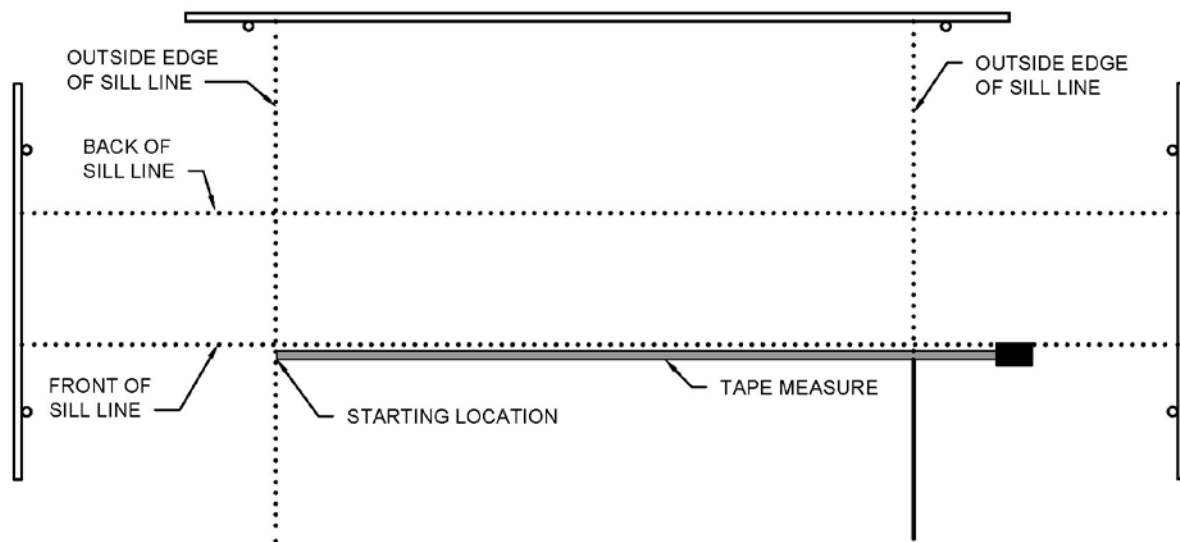
16.9.2.1. Free Standing Concrete Sills

When constructing a concrete sill on top of an earthen or soil/rock filled abutment, the sill is laid out, formed, and poured in the same fashion as the concrete footing as previously described. The concrete sill is framed and poured on top of the earthen or soil/rock filled abutment to separate the bridge stringers from the surrounding soil. The top of the sill is flat and does not have a soil dam incorporated into the concrete pour. J bolts for the beam seat brackets are installed in the sill using the same methods as previously described. The end-of-bridge stringer will sit flush with the back of the sill and is through-bolted to the metal bridge stringer bracket. The soil dam is attached separately.

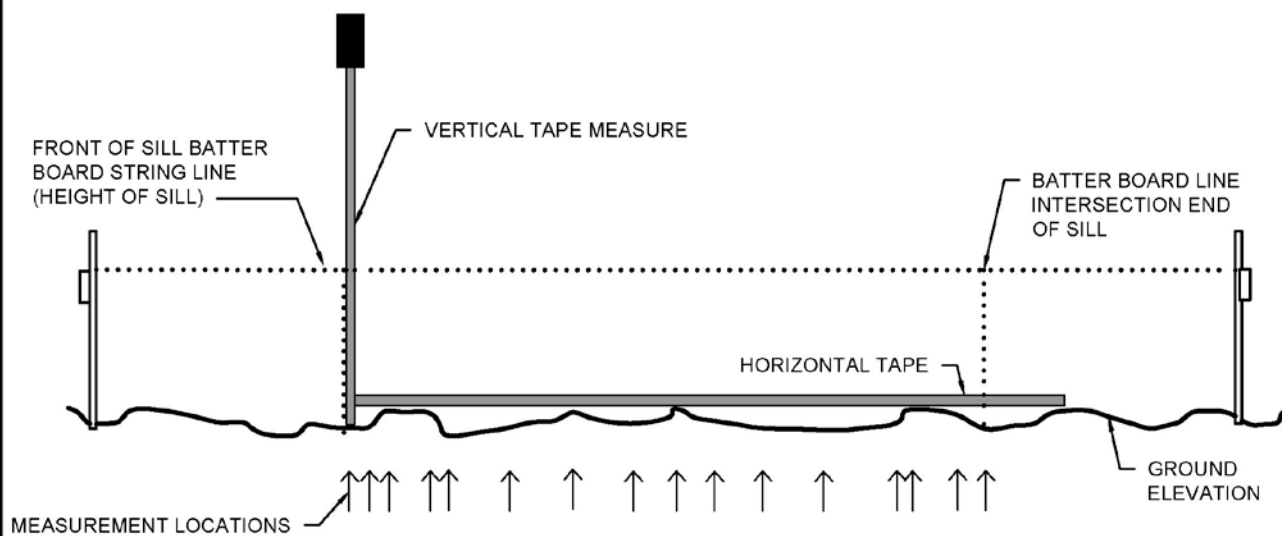
16.9.2.2. Concrete Sills on Bedrock

When constructing a concrete sill on top of bedrock, the native surface must be cleaned of all loose rock, soil, and vegetation. If side and end batter boards and string lines were established during the layout of the abutment, they can be set to identify the outside edges of the sill as well as the elevation. If the bedrock upon which the sill will sit is nearly level, a gas-powered jack hammer and Roto hammer can be used to finish leveling. In most cases, the surface will not be level and trying to level it can require a great deal of time and effort.

An alternative is to design the bottom of the concrete sill form so it matches the irregularities of the surface by developing an elevation graph of the surface. With the string lines in place, lay a tape measure across the bedrock (left to right) in front of the string line that represents the front of the sill and the designed sill height. Starting at the front left corner of the sill, use another tape measure to measure the vertical elevations along the front of the string line. Record the vertical elevation at the left front corner (the intersection of two batter board string lines). Then, move the tape measure laterally along the string line and with every 1/4-inch change in elevation, record the vertical elevation and horizontal location along the front tape measure. Finish by recording the vertical elevation and horizontal distance at the end of the sill (the intersection of the front and side batter board string lines). (See Figure 16.41.) Be sure to keep the tape measure plumb when measuring these elevations. Record the measurements on a site plan. At each station where a measurement was taken, the vertical distance between the surface and the string line, and the corresponding lateral distance along the front tape measure should be recorded. Repeat this task along the string lines that represent the back and sides of the footing.



CONCRETE SILL LAYOUT WITH BATTER BOARD LINES OVERHEAD VIEW



1. LAY HORIZONTAL TAPE MEASURE ON BEDROCK ACROSS FRONT OF SILL OUTLINE USING THE BATTER BOARD STRING LINE AS A GUIDE. THEN HOLD VERTICAL TAPE MEASURE AT THE FRONT LEFT CORNER OF THE SILL OUTLINE USING THE BATTER BOARD LINES AS A GUIDE.

2. MOVING LEFT TO RIGHT TAKE MEASUREMENTS FROM THE ROCK SURFACE TO THE FRONT OF SILL STRING LINE EVERY TIME THERE IS AN ELEVATION CHANGE OF $\frac{1}{4}$ " OR MORE. AT EACH MEASUREMENT LOCATION RECORD BOTH THE VERTICAL AND HORIZONTAL ELEVATIONS. RECORD THESE MEASUREMENTS ON A SITE PLAN. REPEAT THIS PROCESS FOR ALL FOUR SIDES OF THE SILL.

DEVELOPING AN ELEVATION GRAPH FOR THE BEDROCK SURFACE FRONT VIEW

Figure 16.41 - Concrete Sill Form on Bedrock Layout



CONCRETE SILL FORM ON BEDROCK LAYOUT

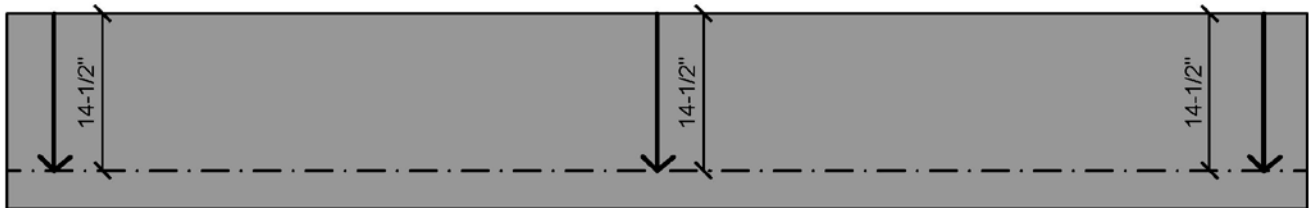
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To transcribe these measurements onto the plywood form boards, lay a piece of plywood cut to the length of the designed sill on two saw horses. Review the recorded measurements and identify the longest measurement. Remember, the longest measurement recorded represents the lowest surface elevation (in this example 14 1/2 inches). Since the measurement was taken from the front string line, which was set at the designed height of the sill, the longest measurement represents the maximum height of the plywood form board. From the top of the plywood sheet, measure down 14 1/2 inches at each end and the center of the sheet and scribe marks at each location. Scribe a line all the way across the plywood sheet, connecting these marks. (See Figure 16.42.) Cut the plywood sheet across this line with a hand saw or powered circular saw.

Once the plywood is cut to the correct height, scribe the elevation measurements previously taken onto it. First, lay a tape measure across the bottom of the plywood sheet (left to right). Begin at the first measurement taken (bottom left corner), then measure horizontally (left to right) following the recorded measurements on the site plan to the next measurement. Scribe marks at the distance across the bottom of the form board that coincides with the measurement previously recorded. Once completed, use another tape measure to measure from the top of the plywood sheet toward the bottom. Note, if the height of the form board is 2 feet or less, a framing square can be used for this measurement, which will keep the measurements plumb. Begin at the top left corner and measure down from the top of the form board by the distance previously recorded and scribe a line at that point. This measurement is taken where the horizontal marks were just scribed. Repeat this process until all of the measurements on the site plan have been recorded. (See Figure 16.43.) Then, use a framing square to scribe a line between each mark. When finished, a jagged pencil line should extend all the way across the bottom of the plywood sheet. Use a coping saw or a powered jig saw to cut off the plywood just below the pencil line. The bottom of the plywood sheet should now closely reflect the surface.

Using the batter board lines as guides, place the sheet of plywood on top of the bedrock to see how it fits. The top of the plywood should be even with the batter board line. If it's too high, use a pencil to mark the locations along the bottom of the plywood where more wood must be removed. Use a saw to make these minor adjustments. Do not worry about small gaps between the plywood and the rock since they can be filled with small rocks or mortar before the concrete is poured. If the gap is not too large, wet concrete will ooze out a little then seal the gap as it hardens. Repeat this process on the back and two end pieces of plywood. Once all the pieces of plywood fit correctly, they can be assembled.



1. USE LONGEST MEASUREMENT FROM THE ELEVATION GRAPH AND MEASURE VERTICALLY THAT DISTANCE DOWN FROM THE TOP OF THE PLYWOOD FORM BOARD AND SCRIBE A LINE. REPEAT IN THE CENTER AND ON OTHER END OF BOARD.

2. SCRIBE A HORIZONTAL LINE BETWEEN THE THREE MEASUREMENTS AND CUT THE PLYWOOD FORM BOARD OFF BELOW THE LINE.

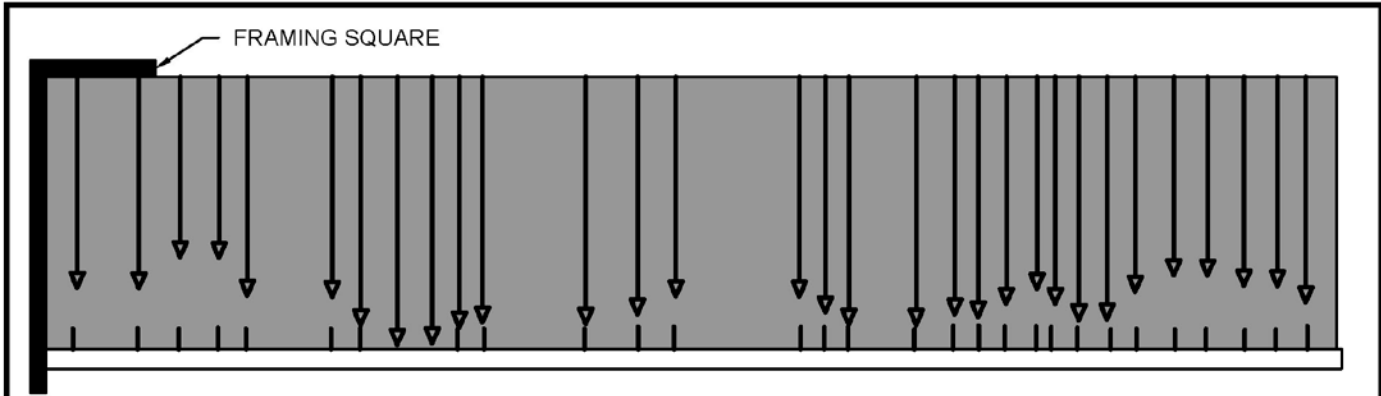
Figure 16.42 - Layout of Sill Height on Plywood Form



LAYOUT OF SILL HEIGHT ON PLYWOOD FORM

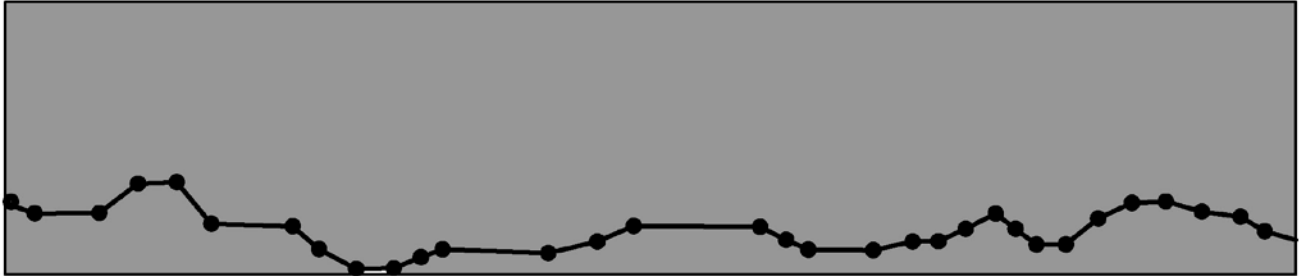
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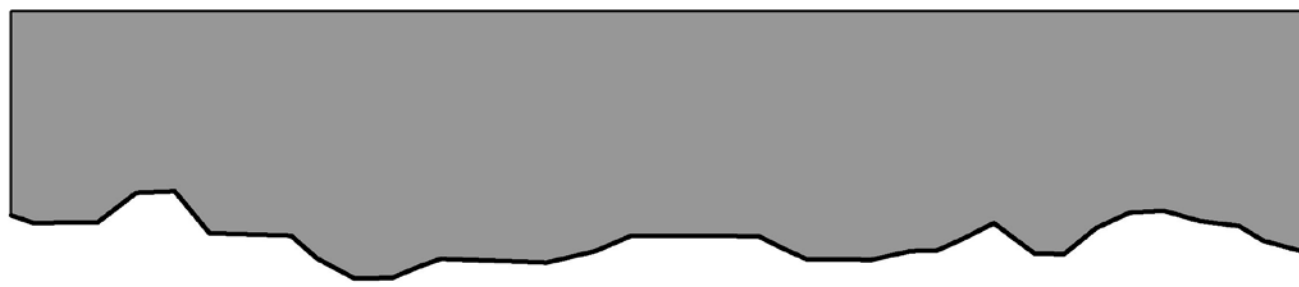


1. LAY A TAPE MEASURE ACROSS THE BOTTOM OF THE PLYWOOD FORM BOARD (LEFT TO RIGHT). STARTING AT THE BOTTOM LEFT FRONT CORNER MEASURE ACROSS THE BOTTOM OF THE FORM BOARD AND SCRIBE MARKS AT THE HORIZONTAL DISTANCES PREVIOUSLY RECORDED DURING THE BEDROCK PROFILE MEASURING PROCESS. ONCE COMPLETE, START AT THE TOP LEFT FRONT CORNER AND MEASURE DOWN THE VERTICAL DISTANCES, PREVIOUSLY RECORDED DURING THE BEDROCK PROFILE MEASURING PROCESS, AND SCRIBE MARKS AT THESE LOCATIONS.

2. ONCE THE FRONT FORM BOARD IS COMPLETED REPEAT THIS PROCESS ON THE BACK AND SIDE FORM BOARDS.



3. USE A FRAMING SQUARE AND CARPENTERS PENCIL TO CONNECT EACH MEASUREMENT SCRIBED. THIS WILL PRODUCE A CONTINUOUS LINE ACROSS THE FORM BOARD. THIS LINE REPRESENTS THE SHAPE OF THE BEDROCK THE FORM IS BEING CONSTRUCTED UPON.



4. USE A JIG OR COPING SAW TO CUT ALONG THE SCRIBED LINE. WHEN COMPLETE THE PLYWOOD FORM BOARD SHOULD CONFORM TO THE SHAPE OF THE BEDROCK.

Figure 16.43 - Layout of Sill Elevations on Plywood Form



LAYOUT OF SILL ELEVATIONS ON PLYWOOD FORM

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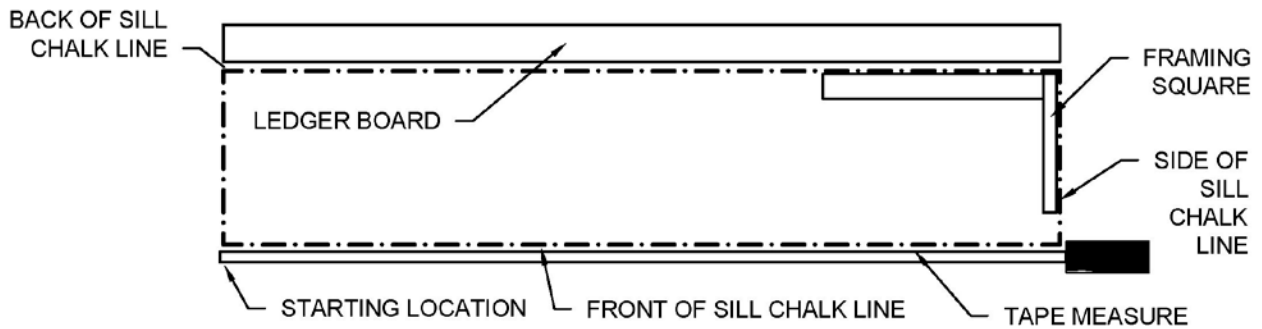
If batter board string lines cannot be used because the bedrock prohibits installing form stakes, this process can be performed using an auto level and stadia rod. (See Figure 16.44.) In the absence of string lines, the outline of the sill must be located and marked on the surface. If batter boards and string lines were not installed, a ledger board can be used for the layout if it is level and square to the bridge alignment. The ledger board will indicate the location of the back of the sill. To complete the outline of the sill, use a framing square and tape measure to locate the sides and ends of the sill. If the ground is very irregular, locating the sides may require the use of a carpenter's level and a plumb bob to ensure the measurement to the front corner is the correct horizontal distance. Once both of the front corners of the sill are located, mark the ends of the sill using a chalk line. Then stretch the chalk line between the two front corners and snap the chalk line to mark the front of the sill.

Lay a tape measure across the front of the forward chalk line as before and use the stadia rod and auto level to take the vertical measurements across the front of the sill. Again the vertical measurements are taken when there is an elevation difference of 1/4 inch or more. This vertical measurement and its horizontal distance along the tape measure are recorded on the site plan. This process is essentially the same as used with the string lines. Again, the highest number on the stadia rod is the lowest ground elevation. Once all the measurements have been taken and recorded, the elevation of the top of the sill must be identified. This elevation is the designed height above the ledger board. For example, the top of the concrete sill is designed to be 12 inches above the elevation of the ground where the ledger board is lying. If the stadia rod reading at the ledger board location is 4 feet then subtract 3 feet from that reading to obtain an elevation of 1 foot. If the lowest elevation is 4 feet 10 inches, then subtract 3 feet from that reading and end up with a measurement of 1 foot 10 inches. This elevation is the highest measurement along the form board and, therefore, the form board is cut to this width. At this point, follow the same process as previously discussed in the batter board string line method.

Prior to pouring concrete, install the reinforcement steel. Since the vertical pieces of rebar cannot be pounded into rock, drill 5/8-inch diameter holes into the rock approximately 6 inches deep with a powered Roto hammer drill. Once the holes are drilled, remove all the rock dust from the hole with a small bottle of compressed air. Once the holes are cleaned, mix a batch of two-part epoxy glue and pour several inches of the glue into each hole. Then, use a sledge hammer to drive the vertical pieces of 5/8-inch rebar into each hole.

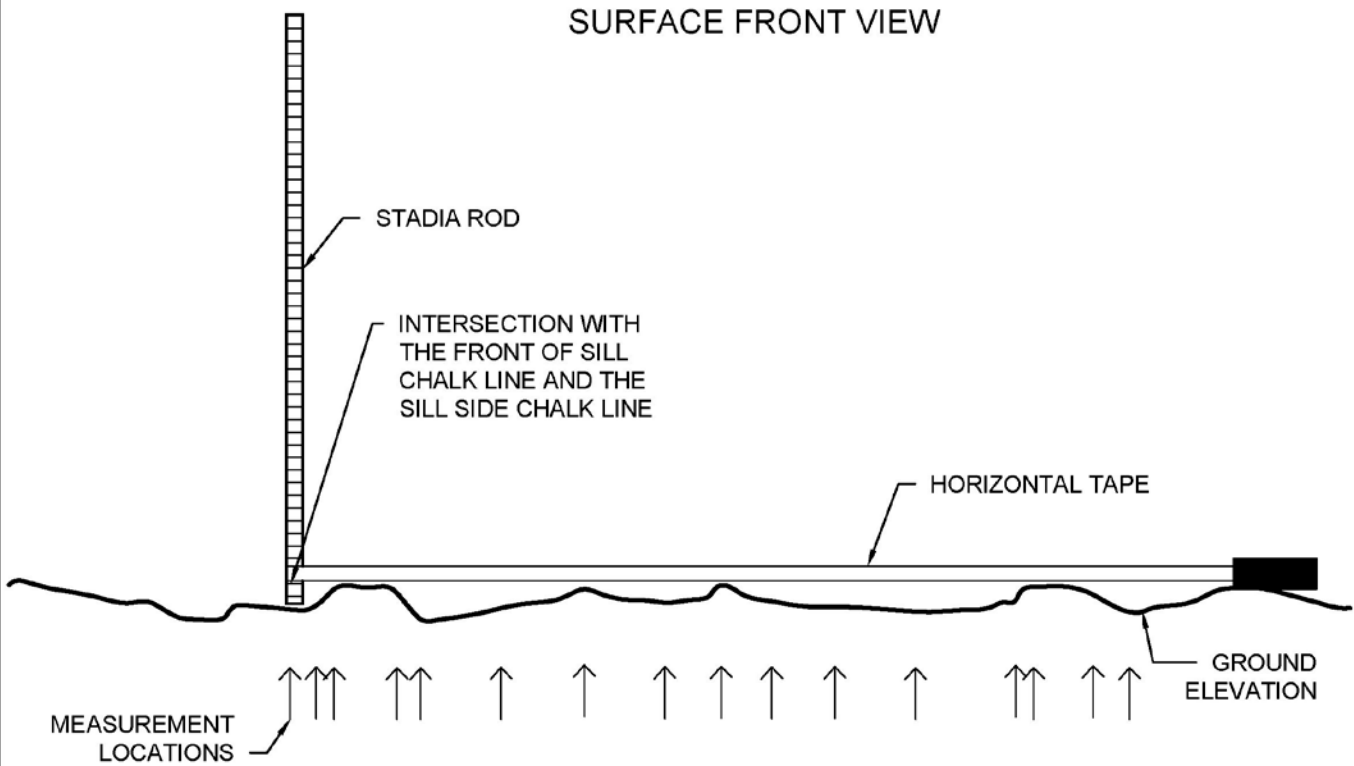
Then, install the remaining rebar, forms, and J bolts. Pour the concrete, remove the form boards, and install the beam seat brackets as previously described. The end of the bridge stringer will sit flush with the back of the sill and is through-bolted to the beam seat brackets. The soil dam is attached separately.

CONCRETE SILL LAYOUT WITH STADIA ROD PLAN VIEW



1. SNAP A CHALK LINE ALONG THE FRONT OF THE LEDGER BOARD TO IDENTIFY THE BACK OF THE FORM OUTLINE. THEN USE A FRAMING SQUARE TO SQUARE UP THE ENDS OF THE FORM OUTLINE AND SNAP CHALK LINES TO IDENTIFY THE ENDS. THEN SNAP A CHALK LINE TO IDENTIFY THE FRONT OF THE FORM.

DEVELOPING AN ELEVATION GRAPH FOR THE BEDROCK SURFACE FRONT VIEW



1. LAY HORIZONTAL TAPE MEASURE ON BEDROCK ACROSS FRONT OF SILL LOCATION USING THE CHALK LINE AS A GUIDE. THEN HOLD STADIA ROD AT THE FRONT LEFT CORNER OF THE SILL OUTLINE USING THE CHALK LINES AS A GUIDE.

2. MOVING LEFT TO RIGHT TAKE MEASUREMENTS FROM THE ROCK SURFACE EVERY TIME THERE IS AN ELEVATION CHANGE OF $\frac{1}{4}$ " OR MORE. AT EACH MEASUREMENT LOCATION RECORD BOTH THE VERTICAL AND HORIZONTAL ELEVATIONS. RECORD THESE MEASUREMENTS ON A SITE PLAN. REPEAT THIS PROCESS FOR ALL FOUR SIDES OF THE SILL.

Figure 16.44 - Layout of Sill Elevations on Plywood Form Continued



LAYOUT OF SILL ELEVATIONS ON PLYWOOD FORM CONTINUED

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16.10. Bridge Stringers

16.10.1. Placing the Bridge Stringers

At this point in the project, the bridge stringers have been transported to the bridge site and are lying on the ground on one side of the watercourse or are spanning across the watercourse above or below the abutments. The options and logistics of transporting the bridge stringers were discussed earlier in this chapter. Some steel bridge manufacturers will specify the use of an elastomeric pad between the beam seat brackets and the bridge stringers. The pad cushions the load from the superstructure to the beam seat or sill. It also accommodates movement of the bridge associated with load and temperature changes (e.g., expansion and contraction). If required, place the elastomeric pads on the beam seat brackets before placing the bridge stringers.

Prior to placing the bridge stringers, be sure they are properly oriented. Log and milled stringers usually are slightly arched or have a “crown.” The crown side should be up when placed on the sills. Similarly, glulam, steel, and fiber reinforced plastic bridge stringers may have an engineered camber. The camber also must be up when the stringers are placed. If the stringers have pre-drilled holes for diaphragms, posts, or similar, make sure they line up to each other.

Make sure all the stringers are the same length. Even manufactured stringers can be off as much as 1/4 inch. Have the stringers on hand and measure them prior to starting a bridge project. Avoid cutting pressure treated stringers because it can compromise the wood treatment. When using log stringers, be sure to alternate the small ends of the logs so the strength of the combined stringers is nearly equal on each end of the bridge.

Bridge stringers can be placed on the sills by hand by a trail crew, by rigging techniques such as high leads and skylines, or by a crane, excavator, or helicopter. During this operation, the trail on either side of the bridge should be closed, barricaded, and manned by a trail crew worker to keep the public out of the hazardous zone.

Manually lifting and placing the bridge stringers is limited to small lightweight stringers and site conditions where the stringers can be carried across the watercourse. (See Photo 16.30.) Although this option may be appropriate in the right setting, it requires the trail crew to climb the streambanks and walk across the stream channel. In many locations, these activities are not appropriate. Carrying bridge stringers also increases the risk of injury to trail crew workers especially when traversing uneven ground with awkward and heavy loads.



Photo 16.30 - Manually Carrying Bridge Stringers

Rigging techniques, such as high leads and skylines, allow the stringers to be lifted, moved, and placed without touching the ground, trampling the streambank, or entering the channel. With the right rigging set and experienced crew, even the largest bridge stringer can be placed with a high degree of control and precision. (See Photo 16.31.) These techniques reduce resource damage and vastly improve worker safety. A skyline is especially utilitarian because it can also be used to transport workers and materials across the watercourse, help assemble the bridge, and provide workers with a safety line. These rigging techniques require “high anchors” near the bridge site in the form of trees or elevated ground above the bridge site with anchor locations such as rock faces, large boulders, or the base of trees. In the absence of natural anchors, tripods can be used as high anchors.

Cranes and excavators are very effective at lifting and placing bridge stringers. They provide good load control and accurate placement. They also improve worker safety and resource protection. (See Photo 16.32.) The use of cranes or excavators is limited to sites with immediate road access such as trailheads. Depending on the location of the project, the cost of this equipment can be high, especially if transporting equipment a long distance.

In a remote or difficult to reach location, a helicopter may be the only solution for transporting bridge stringers. If a helicopter is used, it may be prudent to have the helicopter place the stringers on the sills when they are delivered. (See Photo 16.33.) The size of the bridge stringers dictates the size of the helicopter required. Large bridge stringers require a large helicopter, which is often called a sky crane. Helicopters excel at lifting and rapidly transporting bridge stringers. Accurately placing a stringer on a beam seat bracket is a little more challenging.



Photo 16.31 - Placing Bridge Stringers on Abutments Using Rigging



Photo 16.32 - Using a Crane to Place Bridge Stringers on Abutments

A number of factors can affect the precision of placing a bridge stringer. One factor is “prop wash”, the wind that is generated by the blades of the helicopter. The larger the helicopter, the more wind it generates. In narrow canyons, prop wash is amplified as it bounces off the canyon walls. Prop wash has the power to move stringers around considerably. Site conditions, such as tall trees or a narrow cliff, may dictate the need for a long wire rope. The longer the wire rope attached to the stringer, the more difficult it is for the pilot to control the load and make subtle adjustments. Sliding a 60-foot bridge stringer onto a beam seat bracket with 1/4 inch of space for error can be difficult. The difficulty is compounded if the bridge abutments have soil dams. Then, there may be 1/2 inch of space between the soil dam and the bridge stringer, in addition to the 1/4 inch between the beam seat

brackets and the bridge stringer. If the bridge stringer is uncontrollably and rapidly moving 1 to 2 feet in any direction, the abutment can be seriously damaged.



Photo 16.33 - Using Helicopters to Place Bridge Stringers on Abutments

To help control the bridge stringer during aerial transport, usually ropes (“tag lines”) are tied to both ends of the bridge stringer before it leaves the staging area. When the bridge stringer is lowered over the bridge abutment, workers on the ground grab the tag lines to help stabilize and move the stringer. Radio communication between the ground crew and the pilot is critical during this operation. In addition, v-shaped brackets are sometimes placed on top of the abutment to help guide the stringer onto the beam seat bracket. If site conditions allow, use the helicopter to set the bridge stringer down next to the abutment and then place the stringer using a skyline.

Regardless of the method used to place the bridge stringers, if they cannot be anchored to the abutment sills right away, then 2- x 6-inch boards should be fastened across the top of the stringers to keep them from moving and falling over. Wooden braces against the outside of the stringers may also be required.

Although the trail should have been already closed and barricaded, it is important to place closure signs and install caution tape across the ends of the bridge at the end of each workday. The closure needs to be in effect until the bridge is completed and opened for public use.

16.10.2. Securing and Squaring the Bridge Stringers

Remove the temporary bracing so that the bridge stringers can be moved as required. Inspect the bridge stringers to make sure they are fully resting on the brackets. Sometimes a piece of a wood or a rock lodges between a stringer and its bracket. To remove debris, use a high lift jack to lift the stringer off of the beam seat

bracket. It may be more efficient to use two high lift jacks opposite each other since a single jack can sometimes push the stringer forward as it is lifting. Remove the debris and lower the stringer back down.

Inspect the bridge stringers to ensure that the ends of each stringer are flush with the backs of the sills. If a bridge stringer is not too heavy, it can be moved forward or backward using a rock bar. The high lift jack can be used to lift some of the stringer weight off of the beam seat bracket to increase the effectiveness of the rock bar. For a very large and heavy stringer, it may be necessary to use a manual wire rope hoist to pull the stringer in a particular direction. If a skyline has been installed over the bridge site, the stringer can be lifted and moved with precision by using a manual wire rope hoist attached to the skyline.

Before bolting the stringers to the beam seat brackets, check if they are square to each other by measuring diagonally from the outside end of one stringer across the bridge to the outside end of the other then repeating this measurement on the opposite side. (See Figure 16.45.) If the stringers are square to each other, the measurements will be the same. If they are not, make sure the ends of each bridge stringer are flush with the backs of the sills. In the case of a concrete abutment with a beam seat and a soil dam, make sure the ends of each stringer are equal distances from the soil dam. If they are not flush or equal distances, correct as necessary. Once the position of the stringers has been corrected, repeat the diagonal measurements. If the measurements are not identical, subtract the short measurement from the long measurement and divide that number by two. Move the stringer with the short measurement that distance toward the back of the sill or soil dam. (See Figure 16.45.) Re-check the diagonal measurements and repeat this process until the diagonal measurements are identical.

For example, if one diagonal measurement is 30 feet 6 inches and the other is 30 feet 5 3/4 inches the calculation is as follows:

$$30 \text{ ft. } 6 \text{ in.} - 30 \text{ ft. } 5 \frac{3}{4} \text{ in.} = \frac{1}{4} \text{ in.}$$
$$\frac{1}{4} \text{ in.} \div 2 = \frac{1}{8} \text{ in.}$$

Thus, the stringer measuring 30 feet 5 3/4 inches must be moved 1/8 inch backward. This lengthens the short measurement by 1/8 inch and shortens the long measurement by 1/8 inch.

It is critical to ensure that the bridge stringers are square. If they are not square, the decking will not be square and will have to be custom cut to fit the bridge. In addition, post and railing locations will not be the same for both sides of the bridge.

1. MEASURE DIAGONALLY FROM OUTSIDE CORNER TO OUTSIDE CORNER. IF THE TWO MEASUREMENTS ARE NOT THE SAME SUBTRACT THE SHORT MEASUREMENT FROM THE LONG MEASUREMENT AND DIVIDE THAT NUMBER IN HALF. ($30' 6'' - 30' 5 \frac{3}{4}'' = \frac{1}{4}'' / 2 = \frac{1}{8}''$)

2. TO SQUARE THE STRINGERS SLIDE THE STRINGER WITH THE SHORT MEASURE TOWARDS THE END OF THE MUDSILL ONE HALF THE DISTANCE BETWEEN THE TWO MEASUREMENTS OR $\frac{1}{8}''$. RE-MEASURE AND ADJUST AS NECESSARY.

3. MOVING HALF THE DISTANCE BETWEEN THE TWO MEASUREMENTS SHORTENS THE LONG MEASUREMENT AND LENGTHENS THE SHORT MEASUREMENT EQUALLY.

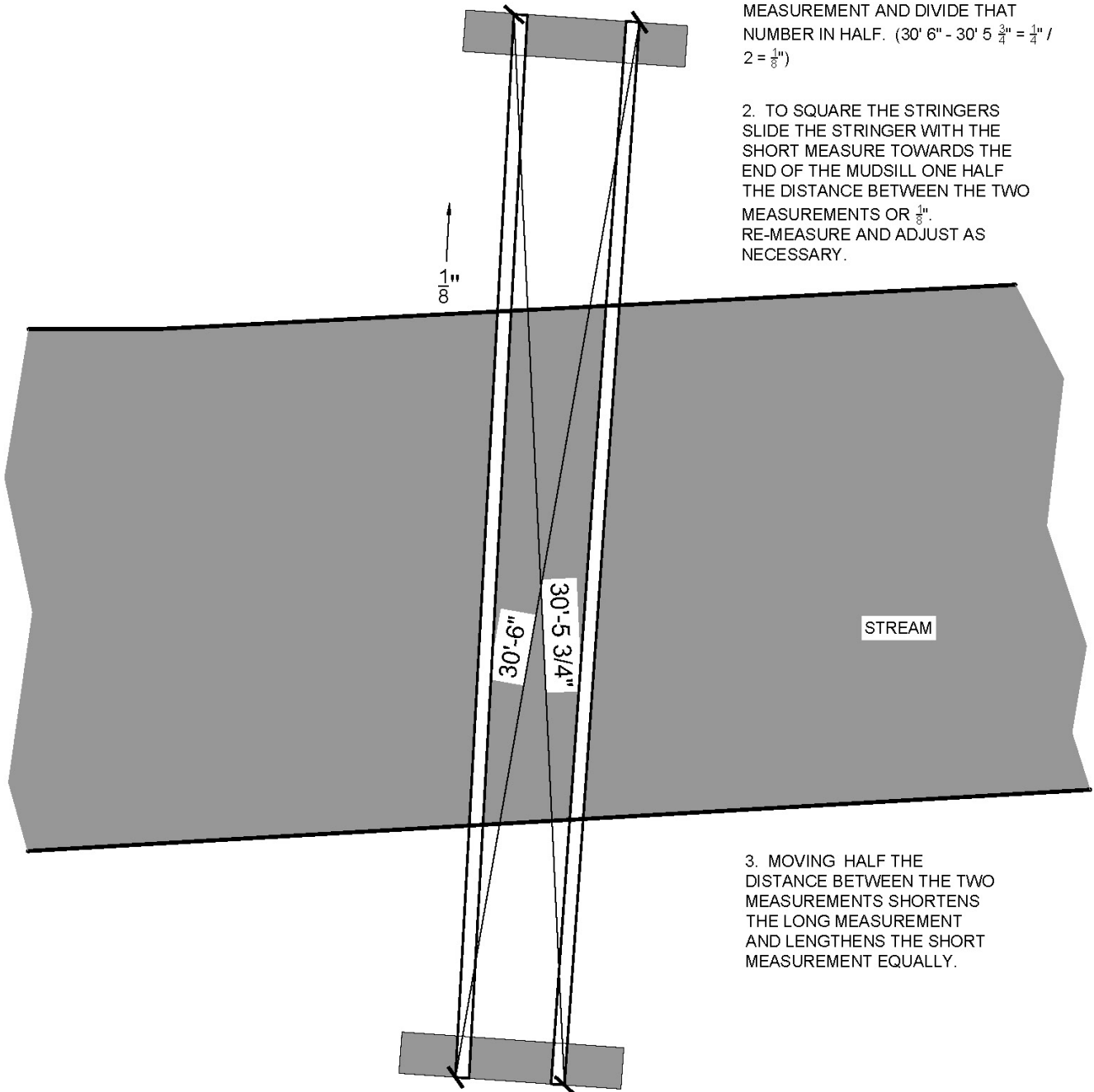


Figure 16.45 - Squaring the Bridge Stringers



SQUARING THE BRIDGE STRINGERS

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Once the bridge stringers are squared to each other, they must be anchored to the beam seats by through bolting to the beam seat brackets. Manufactured glulam, steel, aluminum, and fiber reinforced plastic stringers will have pre-drilled holes for this purpose. Sometimes, after squaring the bridge stringers, the pre-drilled holes may not line up with the beam seat bracket holes. In this case, re-drill or ream out the holes in the stringers using the bracket holes as a guide. A milled wood stringer will need to have holes drilled using the beam seat bracket holes as guides and drilling through the stringer as it is resting on the brackets. Pressure treated wood stringers will need to be treated with a wood preservative after the holes are drilled or reamed. Apply copper naphthenate with a bottle brush for this purpose. Once the stringers are squared and anchored to the beam seats, re-install the temporary bracing.

16.11. Bridge Scaffolding and Skyline

Before work on the bridge can proceed, the workers must have a safe platform from which to work. Unless the bridge stringers are a short distance above the stream channel and workers can assemble the post sills, diaphragms, bridging, and posts or post braces by standing in the channel, some type of temporary scaffolding must be installed. Standard stair tower scaffolding can be assembled in the channel if the channel morphology and water conditions allow. Aluminum scaffolding, which is lighter and easier to transport, can be purchased or rented. However, even under the best circumstances, the unevenness of the channel makes the assembly and operation of this type of scaffolding difficult. Setting-up and moving this system within the stream channel also can have an impact on the channel and streambank.

The Department has developed a bridge scaffolding system that hangs from the bridge stringers. This scaffolding is easy to transport, set-up, and operate. Because it hangs from the bridge, there is no need to enter the stream channel or disturb the streambanks. (See Photo 16.34.) The scaffold decking is hung below the stringers and is adjustable to accommodate varying stringer heights. The scaffold decking is attached both inside and outside of the stringers, allowing workers to safely work on both sides. The scaffolding is designed to roll across the top of the stringers and is highly mobile. See Appendix K for bridge scaffolding drawings and assembly instructions.

When used in conjunction with an overhead skyline, the scaffolding system is safe and highly efficient. The skyline can be used to transport, lower, and secure heavy or awkward bridge components, such as diaphragms or post sills. Loads are attached to a small manual wire rope hoist, which is hung from the skyline on a block. Once attached to the hoist, the load is moved along the skyline via the block. The hoist is used to raise or lower the load as desired. (See Photo 16.35.) In addition, the skyline can serve as a safety line. Workers wearing full arrest body harnesses can be tied off to the skyline with a safety rope. The length of rope can be adjusted for the site conditions by retying the knot. The rope is attached to the skyline with a locking carabineer. A worker can easily slide the carabineer along the skyline to move along the bridge. (See Photo 16.36.)



Photo 16.34 - Bridge Scaffolding Used to Assemble Bridge



Photo 16.35 - Using Skyline, Blocks, and Hoist to Move Loads



Photo 16.36 - Securing Workers to the Skyline

16.12. Installing a Drop Cloth

After the bridge stringers are placed and anchored, a geotextile fabric drop cloth should be installed under the area where the bridge will be assembled. The drop cloth is installed to catch any debris that falls from the bridge as it is being assembled. The cloth prevents fasteners, wood chips, and pressure treated materials from entering the watercourse. It also catches tools and other valuable items that might otherwise be lost in the channel if they are dropped.

The drop cloth spans from one abutment to the other and should be wide enough to extend beyond the outside of the finished bridge by 3 to 4 feet on each side. The drop cloth can be anchored to wooden mudsills via nailing or pinned into the ground in front of non-wooden sills with U-shaped pieces of rebar. The drop cloth should hang far enough below the bridge stringers that it will not interfere with the installation of the post sills or cable truss assembly. The distance between the bottom of the bridge stringers and the water in the watercourse can also be a limiting factor in how low this drop cloth can be installed. If there is insufficient space to install the necessary bridge components, the drop cloth will have to be installed after they are attached to the stringers. (See Photo 16.37.)

16.13. Straightening the Bridge Stringers

Bridge stringers need to be plumb (vertical and at a right angle to the abutments). If they are not plumb, they will not have full load capacity. Twisting and warping of the stringers can even result in the stringers not fully resting on the beam seats. Being out of plumb also will make it difficult to install diaphragms or bridging. The posts and handrails will also be affected. The unintended flare will reduce their strength, make them difficult to assemble, and visually obtrusive.



Photo 16.37 - Installing a Drop Cloth

It is not uncommon for milled wooden and glulam bridge stringers to be warped. Milled wooden stringers are sawn from green logs and rarely kiln dried. While sitting in the sun in a lumber yard or shop area, these stringers will begin to twist unless they are properly stickered and weighted. Although glulam stringers are not nearly as susceptible to twisting, they can develop subtle warping if not properly stored. Warping can also occur after the bridge stringers have been delivered to the bridge site, usually from being laid on their side on uneven ground. Sometimes it only takes a couple of days in this position to warp the stringers. Even metal and fiber reinforced plastic bridge stringers can develop a subtle twist if not properly stored or transported. By visually sighting down the stringers, severe warping can easily be detected. Subtle warping can be detected by holding a 4-foot carpenter's level vertically along the side of the stringers. Most warped stringers can be straightened when diaphragms, bridging, or post sills are installed.

16.13.1. Diaphragms

A diaphragm, also called a channel, is a cross brace that is inserted between the bridge stringers. Once bolted to the stringers, it unitizes, stabilizes, and strengthens

the stringers. It also acts as a spacer to ensure that the stringers are the correct distance apart. Most manufactured wooden glulam, metal, aluminum, and fiber reinforced plastic bridges come with diaphragms. (See Photo 16.38.) Depending on the length and design of the bridge, it may have one to four or more diaphragms. The stringers have pre-drilled bolt holes for attaching the diaphragms.



Photo 16.38 - Steel Diaphragms Between Bridge Stringers

A diaphragm is installed by attaching it to the skyline via a block and manual wire rope hoist. The diaphragm is then pulled along the skyline until it is over the location of the bolt holes. The workers standing on the bridge scaffolding use the manual wire rope hoist to lower the diaphragm between the stringers. Once the diaphragm is in line with the pre-drilled holes, bolts are pushed through the stringers from the outside to the inside, and through the diaphragm. If the stringers are relatively plumb, the bolts will reach all the way through the diaphragm. Washers and nuts are slipped onto the bolts. Insert all the bolts and attach the washers and nuts before tightening the nuts. Use a socket and ratchet or box end wrench to tighten down the nuts evenly so the stringers are pulled together uniformly. Once the diaphragms are installed the stringers should be plumb.

Sometimes a pair of stringers is so warped that the diaphragms cannot be inserted between them. If a stringer is warped inward, insert a high lift jack inside the narrow portion of the stringer and use it to spread the stringers apart. (See Photo 16.39.) Once they are wide enough apart, insert the diaphragm and bolt it down as previously described.

If a stringer is warped outward, the bolts may not reach all the way through the diaphragms because the two stringers will not be parallel for their entire length. For example, the top of one of the stringers may flare outward a greater distance than

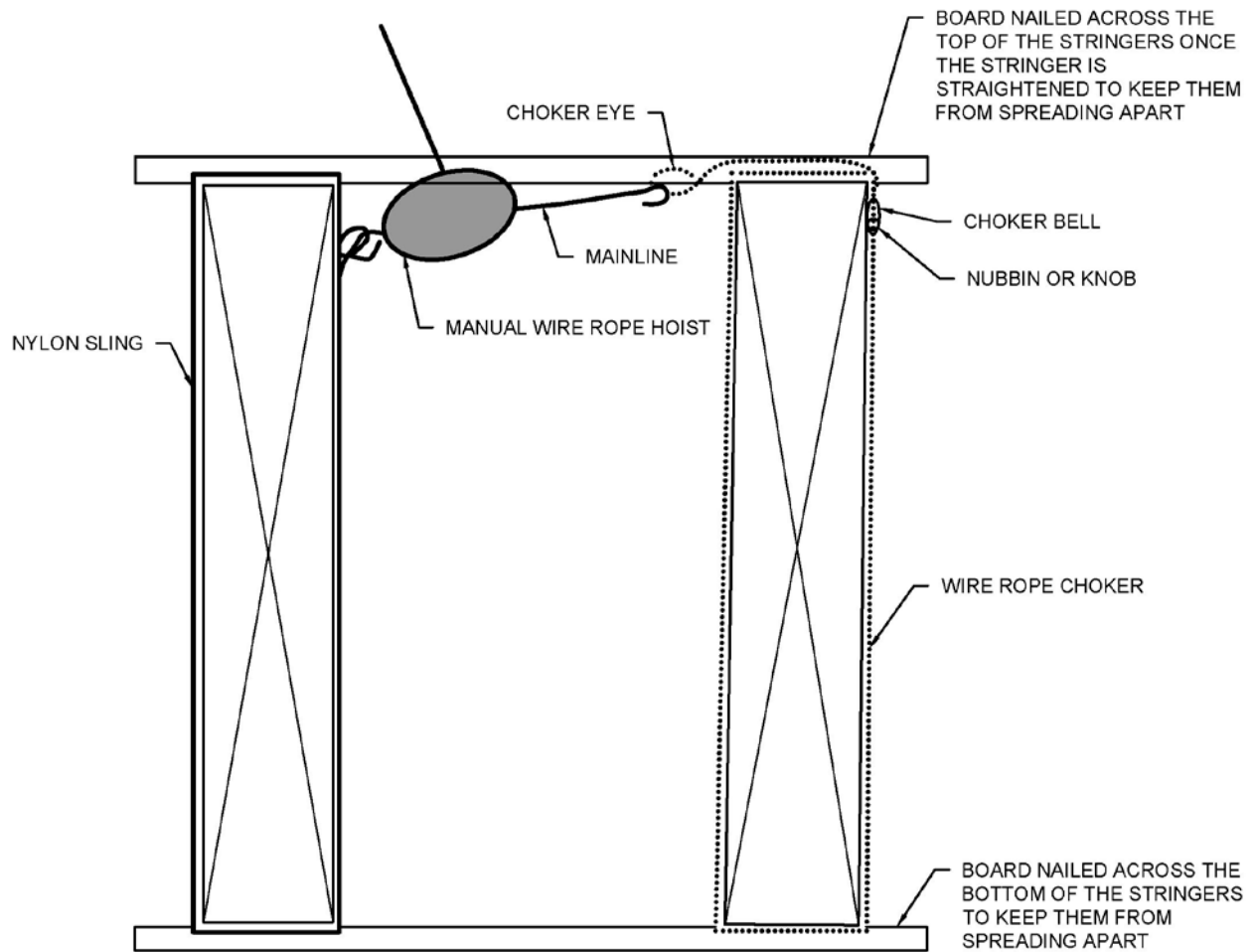
the bottom. If the bottoms of the stringers can be bolted to the diaphragm, it should be done first. To pull the stringers together, attach a manual wire rope hoist to the straight stringer. The location will either be at the top or bottom of the stringer, depending on where the flare is. Attach a choker to the warped stringer so the bell is just on the outside edge of the flared side. Attach the manual wire rope hoist to the choker and take up the hoist slowly. (See Figure 16.46.) The choker set should draw the flared stringer inward. The bolts attached to the narrow ends of the stringers will prevent the ends from pulling apart as the flared end is pulled together. Once the bolts can reach all the way through the diaphragm on the flared end, insert them and tighten as previously described.



Photo 16.39 - Using High Lift Jack to Spread Bridge Stringers

When prying the stringers apart or pulling them together, it is sometimes necessary to attach a board across both stringers (top or bottom) to keep them from moving. For example, if the stringers are warped at the top and are too close together, a high lift jack is inserted at the top between the two stringers to spread them apart. To prevent the bottom of the stringers from being pushed together, a board is attached across the bottom of the two stringers to keep them in place as the top is being pushed apart.

In addition, if only a portion of the bridge stringers are warped, it is good practice to attach boards across the tops and bottoms of those portions before starting to keep them from being twisted out of plumb when other portions of the bridge are being forced into plumb. The boards should be placed where they will not interfere with installation of the posts. The boards can be removed as the decking is installed.



1. NAIL A BOARD ACROSS THE BOTTOM OF THE TWO STRINGERS TO KEEP THEM FROM SPREADING APART WHEN THE TOP OF THE STRINGERS ARE PULLED TOGETHER. WRAP A NYLON SLING AROUND STRAIGHT STRINGER AND CHOKE THE BOTTOM EYE THROUGH THE TOP EYE AT THE TOP INSIDE CORNER.

2. WRAP A WIRE ROPE CHOKER AROUND THE WARPED STRINGER WITH THE BELL ON THE UPPER OUTSIDE CORNER. THE NUBBIN SLIPS IN THE BELL FROM THE BOTTOM TO SET THE CHOKER ROLL AT THE TOP OUTSIDE CORNER OF THE STRINGER.

3. ATTACH THE MANUAL WIRE ROPE HOIST (HOIST) ANCHOR HOOK TO THE NYLON SLING EYE AND ATTACH THE HOIST MAINLINE HOOK TO THE WIRE ROPE CHOKER EYE. PULL ON THE WIRE ROPE CHOKER WITH THE HOIST UNTIL THE STRINGER STRAIGHTENS OUT.

4. ONCE THE STRINGER IS PLUMB, NAIL A BOARD TO THE TOP OF THE STRINGERS TO KEEP THE STRINGER FROM RETURNING TO ITS WARPED POSITION. REMOVE THE GRIPHOIST AND CHOKERS BUT KEEP THE BOARDS IN PLACE UNTIL THE DIAPHRAGM OR BRIDGING AND DECKING IS INSTALLED.

Figure 16.46 - Straighten String with a Manual Wire Rope Hoist



STRAIGHTEN STRINGER WITH A MANUAL WIRE ROPE HOIST

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Some manufactured bridge stringer packages come with sway braces. A sway brace provides additional stability to the bridge by reducing lateral movement. It is attached from the bottom of the diaphragm to the beam seat bracket. The braces are crossed over each other to form a cross brace. (See Photo 16.40.) There are turn buckles at the end of the sway braces that are attached to the beam seat brackets. The turn buckles are tightened until they are taut. If the sway braces are too loose, they will slap or clang together when someone jumps up and down on the bridge. Tighten the turn buckles until they are too taut to slap against each other.



Photo 16.40 - Sway Brace Rods Attached to Diaphragms

16.13.2. Bridging

“Bridging” is another form of wooden cross bracing that is installed between the stringers to unitize, stabilize, and strengthen the stringers. It is usually limited to use with milled wooden stringers or glulam stringers purchased from a lumber supplier. Bridging material is commonly 2- x 12-inch con heart redwood, cedar, or pressure treated Douglas fir. It is cut and installed at alternating 45 degree angles. (See Photo 16.41.) If pressure treated Douglas fir is used, the cut ends must be painted with a wood preservative. The bridging is normally installed in the center of the stringers. The bridging boards are attached to the inside of the stringers with 30d galvanized nails, which can easily be performed when working off of the bridge scaffolding.

Bridging can also be used to straighten the bridge stringers and eliminate minor warping as the bridging is being installed. Once cut to the correct length and angle, the bridging will spread the stringers apart as it is being hammered into place by placing the 45 degree angled ends flush against the stringers. If the stringers are too far apart, the bridging boards will draw them together as they are fastened to the

stringers. If the warping is severe, the stringers will need to be spread or pulled apart and held in place with boards nailed across the bottom or top of the stringers as described above for a diaphragm. The boards are left in place to maintain the correct spacing between the stringers until the bridging and decking is installed.



Photo 16.41 - Wooden Bridging Used to Stabilize Bridge Stringers

16.14. Post Sills

A post sill is a structural member that is attached perpendicularly to the bottom of the bridge stringers. When used in conjunction with decking, it can also unitize, stabilize, and strengthen the stringers. A post sill also provides structural support to the railing post by providing a platform and nailing surface for the post braces. Post sills are commonly used on milled wooden stringers or glulam stringers purchased from a lumber supplier that are 16 inches or less in height. Post sills are 5 1/2 x 7 1/2 inches in dimension and are of con heart redwood or cedar. Note, post sills, post braces, posts, and railings are commonly made from nominal lumber (surfaced on all four sides) and their actual dimensions are 1/2 inch less than stated (e.g., a 6- x 8-inch board is actually 5 1/2 x 7 1/2 inches). Nominal (surfaced) lumber is used to eliminate splinters, expedite sanding, and provide a more aesthetic finish to the bridge superstructure. (See Photo 16.42.)



Photo 16.42 - Installed Post Sills

16.14.1. Post Sill Length

Before laying out the post sills, calculate the length needed. The calculation is the same as that used to determine the length of mudsills when used in conjunction with post sills. The post sill must be long enough that a post brace can be installed at a 45 degree angle with the bottom of the post brace above the decking elevation. Thus, the formula is as follows:

$$L = W + 2H + 3(P + B)$$

L = Post sill length

W = Width of bridge from outside to outside of the stringers

H = Height of stringers

P = Thickness of post

B = Length of the end of the post brace cut at 45 degree angle

For example, a 30-foot milled stringer bridge requires two 10- x 16-inch Douglas fir stringers, is 5 feet wide from outside to outside of the stringers, and has railings and posts that are 4 x 6 inches. Based on these specifications, the minimum post sill length calculation is as follows:

$$L = 60 \text{ in.} + 2(16 \text{ in.}) + 3(3.5 \text{ in.} + 7.5 \text{ in.})$$

$$L = 60 \text{ in.} + 32 \text{ in.} + 33 \text{ in.}$$

$$L = 125 \text{ in.}$$

Thus, in the example above, the required length of the post sills is 125 inches or 10 feet 5 inches.

16.14.2. Number of Post Sills and Posts

Once the length of the post sills has been determined, the required number of post sills is calculated. This calculation must be coordinated with the post and railing layout. The maximum span of the top railing should be 10 feet. To determine the number of post sills required, divide the distance between the end posts by the maximum distance of the railing (i.e., 10 ft.). If the end posts are installed flush with the ends of the stringers then the stringer length is used for the layout calculations. To determine the number of post sills required per stringer, divide the stringer length by 10 feet and add one post sill (30 ft. ÷ 10 ft. = 3; 3 + 1 = 4 post sills). (See Figure 16.47.) Since the mudsills also act as post sills, subtract the two mudsills from the total post sills calculated (e.g., 4 post sills - 2 mudsills = 2 post sills needed). For every post sill and mudsill two posts are required [e.g., 2 x (2 post sills + 2 mudsills) = 8 posts].

Often the length of the bridge stringer is not evenly divisible by 10. In this situation, either add a post to each stringer or move the end posts inward to keep the spans between the posts 10 feet or less. For example, if the bridge stringer length is 32 feet, the number of posts needed is 4.2 (i.e., $32 \div 10 = 3.2 + 1 = 4.2$). Since the number of post sills must be a whole number, either reduce the number of post sills to four or increase it to five. If reduced to four, the span of the top railing would exceed 10 feet. To stay within the maximum span of 10 feet, five post sills are needed (two mudsills and three post sills). (See Figure 16.47.) Alternatively, if each end post is moved inward by 1 1/2 feet, the distance between the end posts would be 29 feet and only four post sills (two mudsills and two post sills) will be needed. (See Figure 16.47.)

16.14.3. Post Sill Layout

To determine the layout of the post sills, divide the distance between the end posts by the number of posts per stringer minus one. This number will be equivalent to the number of open spaces between the posts.

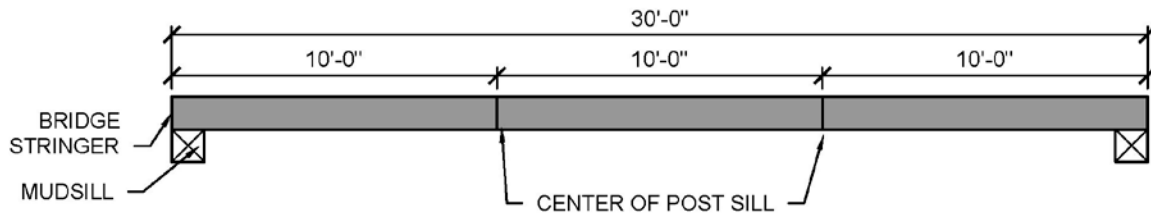
For example, a 30-foot bridge with four posts per stringer would have an average of 10 feet between post sills.

$$\text{Distance between posts} = 30 \text{ feet} \div (4 - 1) = 10 \text{ feet}$$

Similarly, a 27-foot bridge with 4 posts would have an average of 9 feet between post sills.

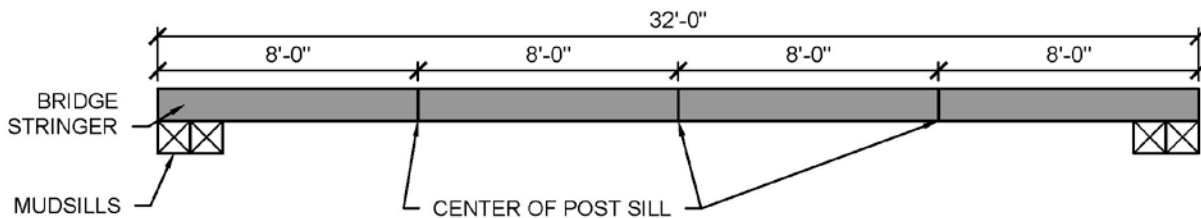
$$\text{Distance between posts} = 27 \text{ feet} \div (4 - 1) = 9 \text{ feet}$$

EXAMPLE #1 (BRIDGE STRINGER DIVISIBLE BY 10)



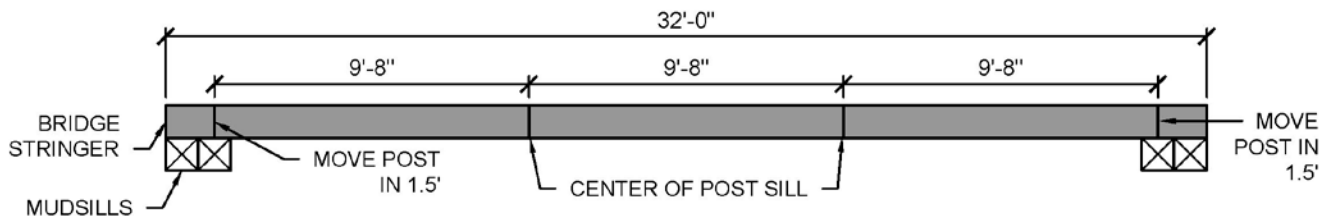
END POSTS ARE SET AT END OF BRIDGE STRINGERS CREATING A TOTAL RAILING SPAN OF 30'. DIVIDE THE RAILING SPAN BY 10' (MAXIMUM SPAN OF TOP RAILING) ($30 / 10 = 3$). ADD ONE POST SILL TO THIS NUMBER ($3 + 1 = 4$ SILLS). SINCE THE TWO MUDSILLS ALSO ACT AS POST SILLS THESE CAN BE SUBTRACTED FROM THE TOTAL ($4 - 2 = 2$ SILLS). 2 POST SILLS ARE REQUIRED.

EXAMPLE #2 (STRINGER NOT DIVISIBLE BY 10, ADD A POST)



END POSTS ARE SET AT END OF BRIDGE STRINGERS CREATING A TOTAL RAILING SPAN OF 32'. TO ELIMINATE RAILING SPANS GREATER THAN 10' AN ADDITIONAL POST IS ADDED $32 / 10 = 3.2 + 1 = 4.2$ SILLS, ROUND UP TO 5 SILLS DUE 10' SPAN LIMIT. SUBTRACT THE 2 MUDSILLS ($5 - 2 = 3$ SILLS) AND 3 POST SILLS ARE REQUIRED.

EXAMPLE #3 (STRINGER NOT DIVISIBLE BY 10, MOVE END POST)



THE TOTAL RAILING SPAN IS 32'. MOVE END POSTS IN 1.5' ON EACH SIDE (3' TOTAL) TO REDUCE RAILING SPAN AND AVOID OVERLAPPING BEAM SEAT BRACKETS ($32' - 3' = 29' / 10 = 2.9$ SILLS + 1 = 3.9 SILLS). ROUND UP TO 4 SILLS AND SUBTRACT THE 2 MUDSILLS ($4 - 2 = 2$ SILLS) AND TWO POST SILLS ARE REQUIRED. NOTE, MOVING THE POST IN AT THE END OF THE BRIDGE WILL REQUIRE RAILING LENGTHS LONGER THAN 10' BUT THE RAILING SPAN WILL BE LESS THAN 10' AS RAILING WILL OVERHANG END POST 1.5'.

Figure 16.47 - Calculating the Number of Post Sills Required



CALCULATING THE NUMBER OF POST SILLS REQUIRED

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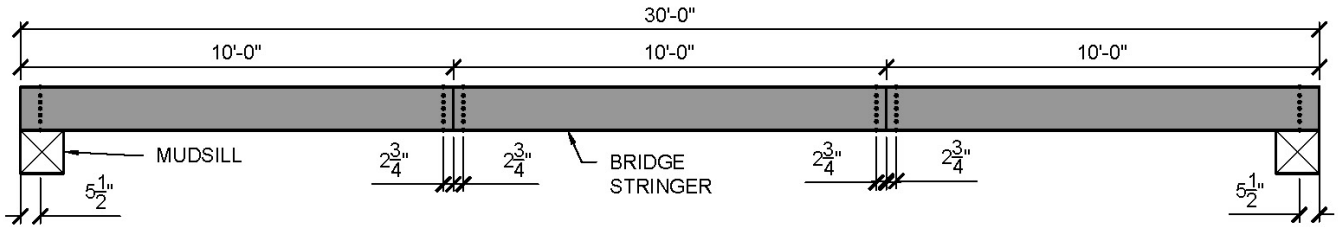
Based on the specifications of the first example above, the layout of the post sills is as follows. (See Figure 16.48.) Begin by hooking a tape measure at one end of the bridge stringers. For milled wooden or wooden glulam stringers without a camber, the tape measure should be hooked at the bottom of the stringers. For glulam stringers with a camber, it should be hooked near but not at the bottom of the stringer to keep the tape level with the bottom of the bridge stringer at its center.

Measure 10 feet and scribe a line where the tape is level on the stringer. This first measurement is from the outside of the first post to the center of the second post. From that first line, measure half the width of the 5 1/2- x 7 1/2-inch post sill (2 3/4 inches) on both sides and scribe those locations. These two lines represent the outside edges of the 3 1/2- x 5 1/2-inch post and the 5 1/2- x 7 1/2-inch post sill. While at this location, lay out the post that will sit on top of the post sill. Using the two lines indicating the outside edges of the post sill (5 1/2 inches wide), scribe vertical lines top to bottom on the outside of the stringer using a framing square. If the stringer has a camber, a carpenter's level should be used to scribe the vertical lines to ensure the lines are plumb. Then, use a framing square to transpose those two lines to the bottom of the stringer.

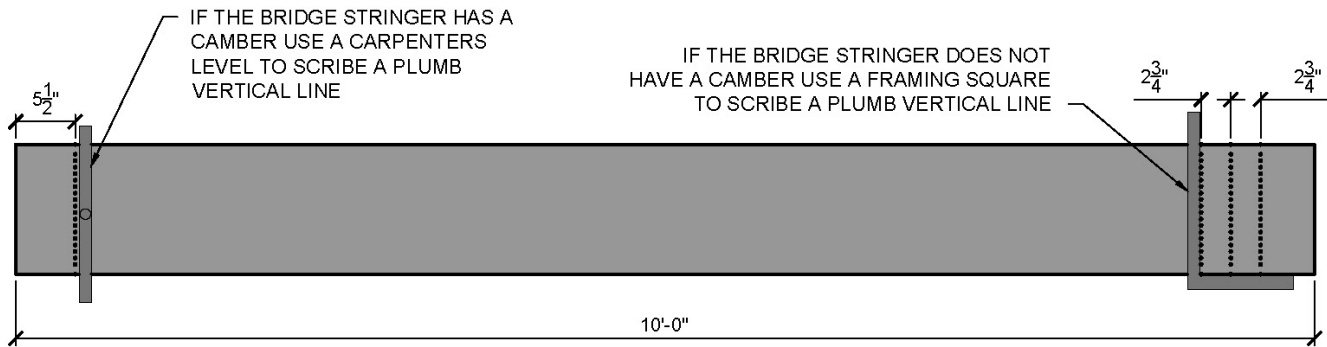
Next, measure another 10 feet across the bottom of the stringer and repeat the process just performed. This measurement is from the center of the second post to the center of the third post. After the third post and post sill locations are scribed, measure another 10 feet. This measurement should extend to the end of the stringer. Remember, the mudsills are used for the post sills on the ends of the bridge stringers. Measure 5 1/2 inches back from the end of the stringer and scribe a vertical line. Between this line and the end of the stringer is where the second end post is attached. (See Figure 16.48.) Once the layout on the first stringer is completed, repeat the layout process on the other bridge stringer. Again, with the bridge scaffolding in place, the layout process can occur on both stringers simultaneously. When completed, the locations for the post sills and the corresponding posts will be scribed.

16.14.4. Post Sill Assembly

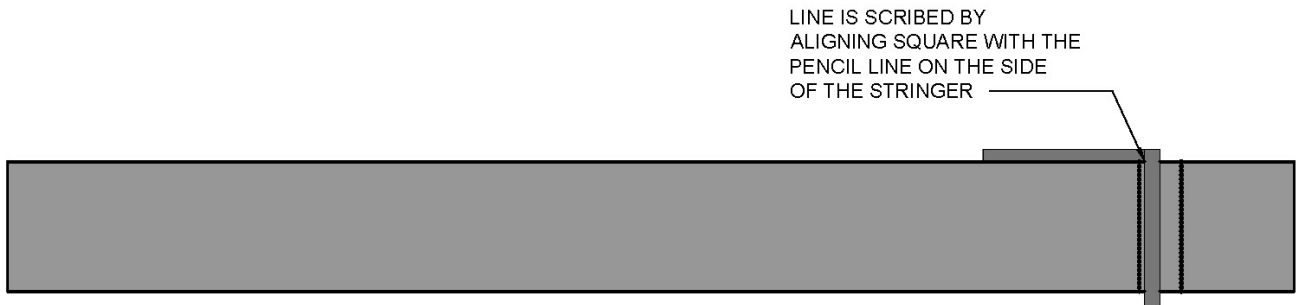
Prior to attaching the post sills, a simple layout process is performed to ensure the post sills are centered on the stringers once attached. With the 6-inch side of the 6- x 8-inch post sill facing up, measure the total length of the post sill and divide it in half. Then measure that distance from one end of the post sill toward the center of the post sill and use a framing square to scribe a line at a right angle across the post sill at that location. Next, from that center line, measure outward 30 inches (half the outside to outside stringer measurement). At that location, use the framing square to scribe a line at a right angle across the post sill. Repeat this layout on the other side of the center line. These two outside lines can now be used as guides to center the post sill when it is attached to the stringers. These lines will be even with the bottom outside edge of the stringers when it is centered.



FROM ONE END OF THE BRIDGE STRINGER MEASURE HORIZONTALLY $5 \frac{1}{2}$ " AND SCRIBE A LINE. USE THE FRAMING SQUARE TO SCRIBE A LINE THE FULL HEIGHT OF THE STRINGER. LOCATED INSIDE THIS LINE IS THE END POST. MEASURE 10' ACROSS THE STRINGER AND SCRIBE A SECOND LINE. MEASURE $2 \frac{3}{4}$ " ON BOTH SIDES OF THIS LINE AND USE THE FRAMING SQUARE TO SCRIBE TWO LINES THE HEIGHT OF THE STRINGER. INSIDE THESE LINES IS THE LOCATION OF THE NEXT POST. THEN FOLLOWING THESE TWO VERTICAL LINES USE A FRAMING SQUARE TO SCRIBE TWO LINES ACROSS THE BOTTOM OF THE BRIDGE STRINGER. BETWEEN THESE TWO LINES IS THE LOCATION OF THE POST SILL. FROM THE 10' LINE MEASURE HORIZONTALLY ANOTHER 10' AND REPEAT THIS PROCESS. AT THE END OF THE BRIDGE STRINGER MEASURE HORIZONTALLY TOWARDS THE CENTER OF THE STRINGER $5 \frac{1}{2}$ " AND SCRIBE A LINE. USE THE FRAMING SQUARE TO SCRIBE A LINE THE FULL HEIGHT OF THE STRINGER. LOCATED OUTSIDE THIS LINE IS THE OTHER END POST.



SIDE VIEW OF POST SILL LAYOUT 10' SECTION OF STRINGER



BOTTOM VIEW OF POST SILL LAYOUT 10' SECTION OF STRINGER

Figure 16.48 - Post Sill and Post Layout



POST SILL AND POST LAYOUT

CALIFORNIA STATE PARKS

NOT TO SCALE

Post sills are attached to the bottom of the stringers. They can be anchored to the stringers with Simpson face mounted hangers, girder hangers, or lag screws. The difficulty in attaching the post sills is holding them in place while the hangers or lag screws are secured. This problem can be overcome by wrapping a nylon strap around the post sill and attaching the strap to a manual wire rope hoist that is hung from the skyline. The hoist is used to pull the post sill up against the bottom of the stringer. Holding the post sill against the bridge stringer can also be accomplished by laying a 4- x 6-inch board across the top of the stringer and attaching two ratchet straps from the 4- x 6-inch board to the post sill. The ratchet straps are then tightened to pull the post sill tight against the bottom of the stringer. (See Figure 16.49.) Metal pipe clamps can also be used by placing one end on top of the stringer and the other under the post sill. Pipe clamps are then tightened by pulling the post sill up against the bottom of stringer.

Working from the bridge scaffolding, the post sill is positioned over the lines scribed on the bottom of the stringer during the post sill layout. Then, the post sill is adjusted laterally until the two lines marking the outside edges of the stringers match up with that location. Once all the layout lines match up, tighten the post sill against the bridge stringer so that it is held securely in place.

If lag screws are used to anchor the post sills, use two 12- x 1/2-inch galvanized lag screws for each end of the post sill. Pilot holes 3/8 inch in diameter and approximately 10 inches deep should be drilled for the lag screws. The pilot holes should be offset so as not to weaken the post sill and placed far enough from the edge of the post sill that the lag screws will not splinter out along the edge of the stringer. The lag screws with washers are then screwed into the pilot holes with a socket and impact wrench or a socket and a ratchet wrench. Caution should be used when tightening the lag screws especially in dry lumber because they can shear off. If one gets too tight, back the lag screw out and drill the pilot hole deeper. Lubricating the lag screws with hand soap also make this task easier.

If face-mounted or girder hangers are used, the hangers are slipped under the post sills so they cradle the post sill. The flanges of the hangers lie flat against the side of the stringer. The hangers are attached to the post sills and stringers via galvanized nails, wood screws, or lag screws, depending on the style of hanger. It is recommended that a hanger be used on both the inside and outside of the stringer for a total of four hangers per post sill.

A final note on post sills: if the standards for the bridge or building materials require that the surface be worked for a hand hewn look (e.g. draw knifed), it is best to do this work before the post sill is attached. The top of the post sill can be left flat so a tight fit between the post sill and the knee brace is easier to achieve, but the corners can be skinned off a little for a more rustic appearance.

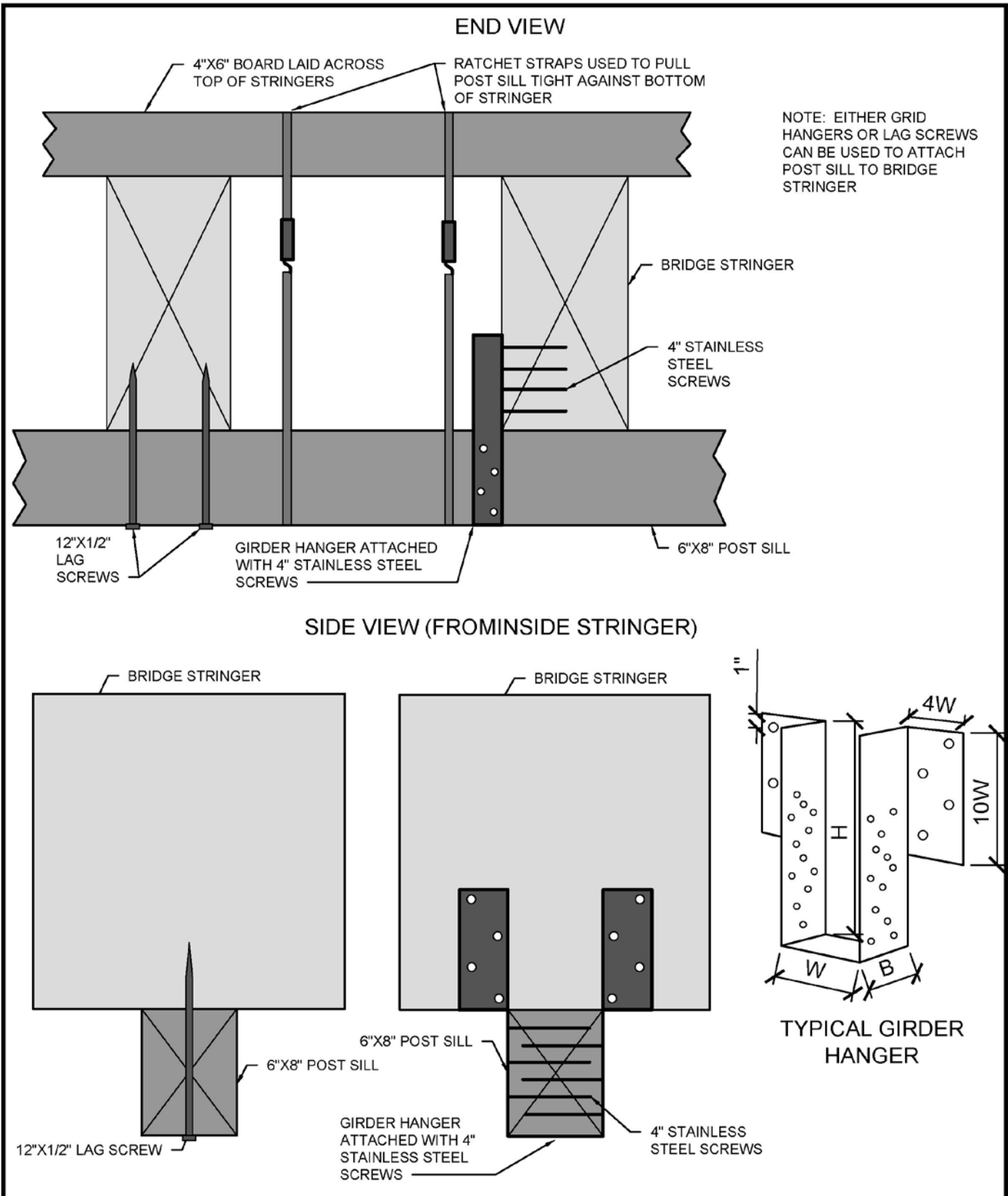


Figure 16.49 - Attaching Post Sill to Stringer

Note, layout and installation of the post sills, posts, and post braces should be performed at the same time. It is more efficient to accomplish these tasks while the bridge scaffolding is located at each post sill rather than working all the way across the bridge and coming back for the next bridge component.

16.15. Posts

Posts are the structural members of the bridge used to anchor the railing. They provide structural support for the railing both vertically and horizontally. A railing is required on all bridge or boardwalk structures higher than 48 inches from the deck to ground. Posts are 4- x 6-inch con heart redwood or cedar.

16.15.1. Post Height

The height (i.e. length) of a post is determined by the standard for the finished railing and the combined height of the beam seat bracket (for posts attached to sills or beam seats), bridge stringer, decking, and railing (after notching). Note, 4- x 6-inch S4S rails are commonly used as the top rail. Because the real dimensions of this lumber are 3 1/2 x 5 1/2 inches and the notching depth is 1 1/2 inches, the top railing is typically 4 inches high. The finished railing height is measured from the top of the decking to the top of the top railing. This height should be 42 inches for pedestrian and bike trails and 54 inches for equestrian trails. On accessible trails with vistas, the height should be modified to less than 32 inches or more than 51 inches to allow for unobstructed viewing, as long as it does not pose a safety concern. The formula for calculating the length of a post is as follows:

$$T = S + D + F - Q - R$$

T = Height of post

S = Height of stringer

D = Thickness of decking

F = Height of top railing above decking

Q = Height of brackets above the top of the mudsill (including elastomeric pad, if applicable)

R = Height of top railing minus depth of notch

For example, a pedestrian bridge with 16-inch high bridge stringers, 3-inch high decking, 42-inch high railings, a 1/2-inch high beam seat bracket, and 5 1/2-inch high top railings notched by 1 1/2 inches, requires posts that are 56 1/2 inches long.

$$T = 16 \text{ in.} + 3 \text{ in.} + 42 \text{ in.} - 1/2 \text{ in.} - (5 \text{ 1/2 in.} - 1 \text{ 1/2 in.}) = 56 \text{ 1/2 in.}$$

If the posts are not set on a beam seat bracket, they need to be 57 inches long.

$$T = 16 \text{ in.} + 3 \text{ in.} + 42 \text{ in.} - 0 \text{ in.} - (5 \text{ 1/2 in.} - 1 \text{ 1/2 in.}) = 57 \text{ in.}$$

16.15.2. Number of Posts

To determine the number of posts required, follow the same process used for determining the number of post sills required. First, identify where the end post will be located. The end post may be placed at the end of the bridge stringer or it may be moved inward to keep the center distance between the posts at 10 feet or less or to avoid the beam seat bracket. The side of the beam seat bracket and its bolts project out beyond the side of the bridge stringer. Moving the post forward of the bracket eliminates the notching that is required if the post is installed against the bracket. Measure the distance between end posts, divide it by 10 (the maximum span of the top rail), and add one. If the resulting number is not whole, round the number up. Double that number to account for the posts on the opposite side of the bridge to determine the total number of posts required.

For example, a 30-foot bridge with end posts will require 8 posts:

$$\begin{aligned}30 \div 10 &= 3 \\3 + 1 &= 4 \\4 \times 2 &= 8 \text{ posts required}\end{aligned}$$

A 38-foot bridge with end posts will require 10 posts:

$$\begin{aligned}38 \div 10 &= 3.8 \\3.8 + 1 &= 4.8 \text{ (round up to 5)} \\5 \times 2 &= 10 \text{ posts required}\end{aligned}$$

A 30-foot bridge with the end posts moved in 1 foot on each end to avoid beam seat brackets will require 8 posts:

$$\begin{aligned}30 \text{ ft.} - 2 \text{ ft.} &= 28 \text{ ft.} \\28 \div 10 &= 2.8 \\2.8 + 1 &= 3.8 \text{ (round up to 4)} \\4 \times 2 &= 8 \text{ posts required}\end{aligned}$$

A 34-foot bridge with the end posts moved in 2 feet on each end to avoid railings longer than 10 feet will require 8 posts:

$$\begin{aligned}34 \text{ ft.} - 4 \text{ ft.} &= 30 \text{ ft.} \\30 - 10 &= 3 \\3 + 1 &= 4 \\4 \times 2 &= 8 \text{ posts required}\end{aligned}$$

16.15.3. Post Layout

The layout process for posts is nearly identical to the layout process for post sills. To determine the layout of the posts, divide the distance between the end posts by

the number of posts per stringer minus one (this number should equal the number of open spaces between the posts).

For example, a 30-foot bridge with four posts per stringer will have 10 feet between posts:

$$30 \text{ feet} \div (4 - 1) = 10 \text{ feet}$$

A 27-foot bridge with 4 posts per stringer will have an average of 9 feet between posts:

$$27 \text{ feet} \div (4 - 1) = 9 \text{ feet}$$

To layout the post locations on the bridge stringers, follow the same process previously described for laying out the post sills. The only difference is that the lines scribed along the bottom of the stringers are eliminated.

When purchasing wooden glulam, all weather steel, aluminum truss, or fiber reinforced plastic I beam bridge stringers from a manufacturer, it is important to provide the manufacturer with a simple set of plans that identify the post layout. The manufacturer will then pre-drill the post attachment holes in the stringers. Any time holes are drilled through a bridge stringer, its load capacity is reduced. If the manufacturer knows the locations of the holes, the stringer can be engineered to compensate for the load reduction. If the bridge stringer is to be made of pressure treated wood, the holes can be drilled prior to being injected with wood preservative.

Note, the engineered all weather steel I beam, aluminum truss, and fiber reinforced plastic I beam bridge designs in Appendix I were developed with drill holes factored into the calculations. However, the layout for the post attachments will need to be submitted to the manufacturer.

Even when the post attachment holes are pre-drilled, the post layout and associated scribing must be performed to ensure that the posts are attached at the proper location and are plumb.

16.15.4. Post Assembly

Once the post layout has been completed, attaching the posts to the stringers is relatively easy. For pre-drilled wooden glulam stringers, the pre-cut posts are laid against the outside of the stringer using the scribed lines as guides. Once the posts line up with the lines, use C-clamps, wooden hand clamps, bar clamps, or deep throat clamps to secure the posts to the stringer. Then, hold a carpenter's level against the side of the post to ensure that it is plumb. If the layout was performed properly the post should be plumb. If not, loosen the clamps and make the necessary adjustments. Once the post is plumb and the clamps have been re-tightened, the bolt holes for the post can be drilled. Use the pre-drilled holes in the stringer as a guide. From the inside of the stringer, slide the appropriately-sized

auger bit through one of the holes in the bridge stringer. Keeping the drill bit plumb and level, drill through the post until the tip of the auger bit just begins to break through the outside of the post. Drill out the remaining holes in the same manner. Finish drilling the holes from the outside of the post using the small hole left by the auger tip as a guide. Note, if the auger bit is pushed all the way through the hole, the outside or face of the post will splinter.

After all the holes have been drilled, insert a galvanized carriage bolt or hex headed bolt with a malleable washer through the outside of the post and through the stringer. Slip a washer and nut over the end of the bolt and tighten the nut down with a deep well socket and ratchet wrench. Depending on the length of the carriage bolt, a box or open end wrench may be needed to finish tightening the nut. Repeat this process for the remaining posts.

When installing an end post against the side of a beam seat bracket, measure the portion of the bracket that the post will be lying against. Also measure the depth or thickness of the bracket. Draw a simple sketch of the post and transpose the measurements onto the sketch. The sketch helps visualize the notching. Layout those measurements on the post and mark the sides of the post to indicate the proper depth of the notch. Use a wood chisel or beveled hatchet to remove the wood from the post at the appropriate locations. Be careful not to remove too much wood. Once the wood has been removed, hold the post plumb against the stringer and bracket to see how it fits. Note any adjustments or further notching that might be required. Sometimes by placing a wooden block against the outside bottom of the post and striking it with a hammer will create an impression in the wood on the inside of the post. This impression identifies the location where more wood needs to be removed. Continue this process until the post lays flush against the stringer.

When ordering all weather steel I beam stringers, metal gussets can be welded to the sides of the beam where the post will be attached. The gussets are pre-dilled to facilitate bolting the post. (See Photo 16.43.) Attaching the post to the stringer is performed in the same manner as described above.

Fiber reinforced plastic I beam stringers can be ordered pre-drilled to facilitate attachment of the posts to the I beam stringers. They also can be drilled on-site. To eliminate the void between the I beam and the post, a 4- x 6-inch wooden block is inserted between the post and the I beam (between the flanges). The pre-drilled holes in the I beam are used as templates for drilling through the wooden block and the post or they can be drilled and attached after laying out the post as described below. (See Photo 16.44.)



Photo 16.43 - Gussets Welded to Steel Stringers to Receive Posts



Photo 16.44 - Wooden Block Used to Bolt Post to Fiber Reinforced Plastic I Beam

Attaching posts to bridge stringers that do not have pre-drilled holes is nearly the same as for those that do. The key difference is prior to clamping the post to the stringer, the bolt hole layout pattern is scribed on the post and the bolt holes are drilled in the post. Again, an alternating hole pattern is used to minimize splitting or weakening of the post. (See Figure 16.50.) After the post has been clamped to the bridge stringer, the holes in the post are used as a guide for drilling through the stringer. The holes in the stringer are drilled from the outside of the post to the inside of the stringer keeping the auger bit level and plumb. Again, do not push the auger bit all the way through the stringer. Finish drilling the hole from the inside of the stringer. Holes made in wooden stringers should be painted with a wood

preservative to reduce rot. Copper naphthenate applied with a bottle brush should suffice. The post is attached with carriage bolts as previously discussed.

If a post sill was installed, the post will sit on top of the post sill. In addition to the carriage bolts, the bottom of the post is toe nailed to the post sill with galvanized 30d nails. Pilot holes 3/16-inch in diameter should be drilled for the 30d nails. (See Figure 16.51.)

16.16. Post Braces

Post braces are used in conjunction with post sills. A post brace is 4- x 6-inch con heart redwood or cedar. It provides additional lateral support for the post. The post brace spans from the top outside edge of the post sill to the side of the post above the decking at a 45-degree angle. (See Figure 16.53.)

To determine the length of the post brace, measure from the bottom outside of the post to the end of the post sill. Then, measure up the post from the bottom by that distance. Mark that location and scribe a horizontal line across the post with a framing square. Then, measure diagonally from that line to the end of the post sill. This measurement is the length of the post sill when it is cut with two 45 degree angles. (See Figure 16.52.)

To layout the post braces, lay a 4- x 6-inch board with the 3 1/2-inch dimension facing up. The side facing up will be the top of the post brace. At the end of the 4- x 6-inch board, measure in 1/2 inch and scribe a 90 degree line across the board. Always avoid scribing the line right at the end or edge of the board because it can be difficult to keep the saw within its kerf when cutting across the board. Then, measure 33 1/4 inches from that line down the board and scribe a second 90 degree line across the top of the board. Flip the board on its side with the 5 1/2-inch dimension facing up. Then, lay a combination square set at 45 degrees along the bottom edge of the board. Slide it across the bottom of the board until the edge of the square's blade and the first line scribed across the top of the board intersect. Then, scribe a 45 degree line across the side of the board. Perform this same process to scribe an opposing 45 degree angle on the other end of the board. Once the two 45 degree lines are scribed, flip the 4- x 6-inch post brace so the bottom is facing up. Then, lay a framing square along the bottom edge of the board. Slide it across the bottom until the edge of the square's blade and the first 45 degree line scribed across the side of the board intersect. Then, scribe a 90 degree line across the bottom of the board. Repeat on the other end of the board. This provides three lines to guide the saw cut: one each at the top and bottom at 90 degree angles and one on the side at a 45 degree angle. (See Figure 16.53.)

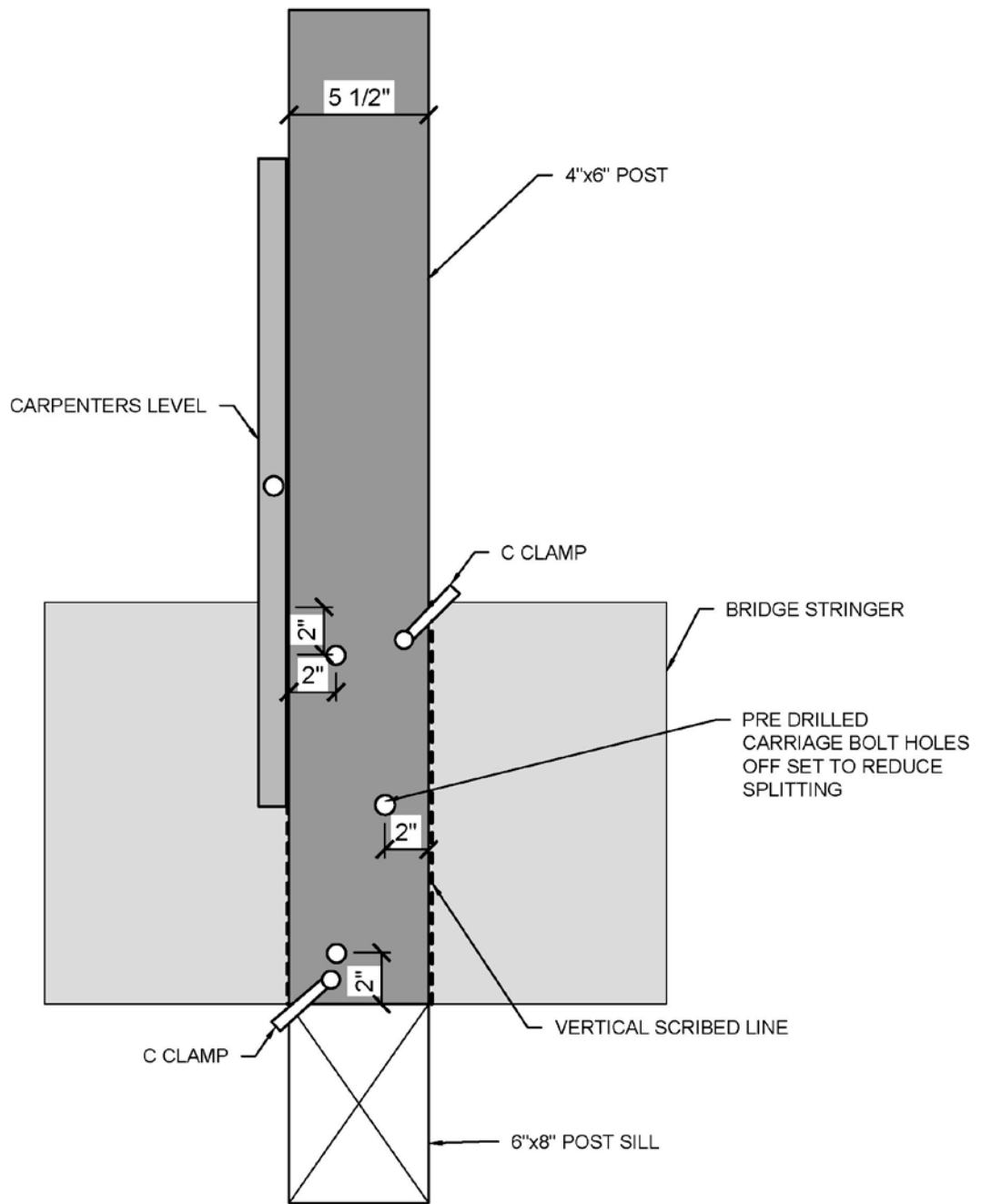


Figure 16.50 - Post Attachment and Carriage Bolt Hole Pattern



POST ATTACHMENT AND CARRIAGE BOLT HOLE PATTERN

CALIFORNIA STATE PARKS

NOT TO SCALE

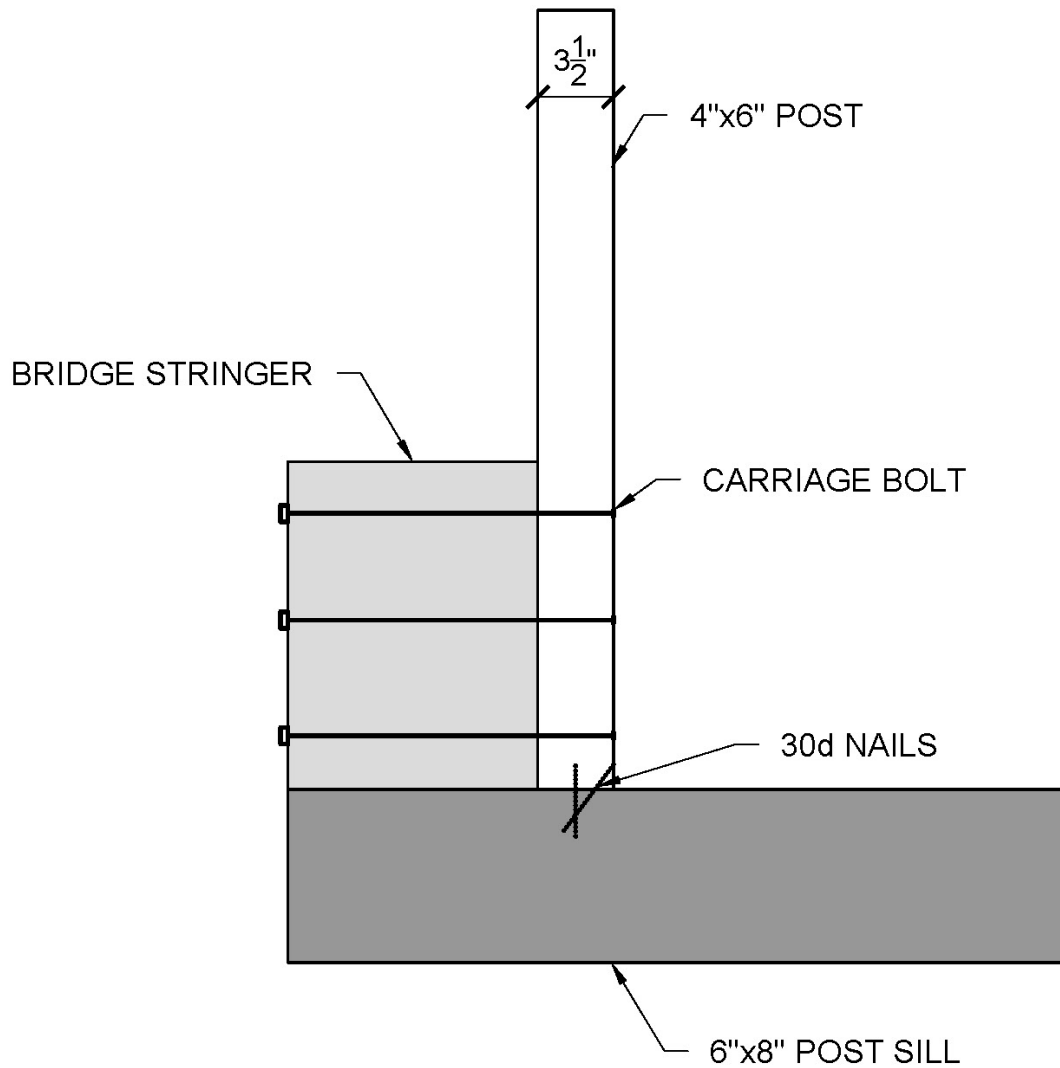


Figure 16.51 - Post Attachment Nailing Pattern



POST ATTACHMENT NAILING PATTERN

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NOT TO SCALE

1. MEASURE FROM THE OUTSIDE BOTTOM EDGE OF POST TO END OF POST SILL. THEN MEASURE THAT DISTANCE FROM THE BOTTOM OF THE POST UP THE POST AND SCRIBE A HORIZONTAL LINE ACROSS THE POST. THEN MEASURE FROM THAT LINE (DIAGONALLY) TO THE END OF THE POST SILL. THAT MEASUREMENT IS THE LENGTH OF THE POST BRACE.

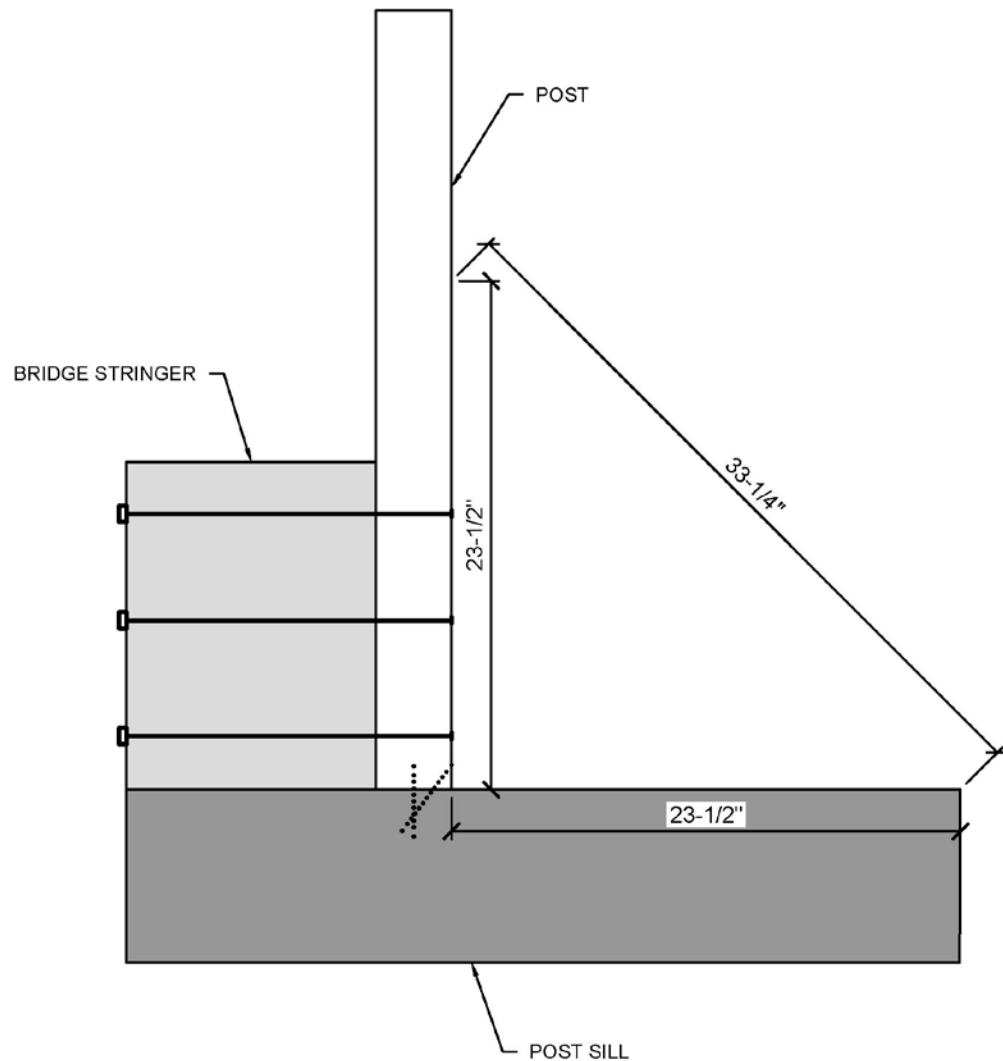


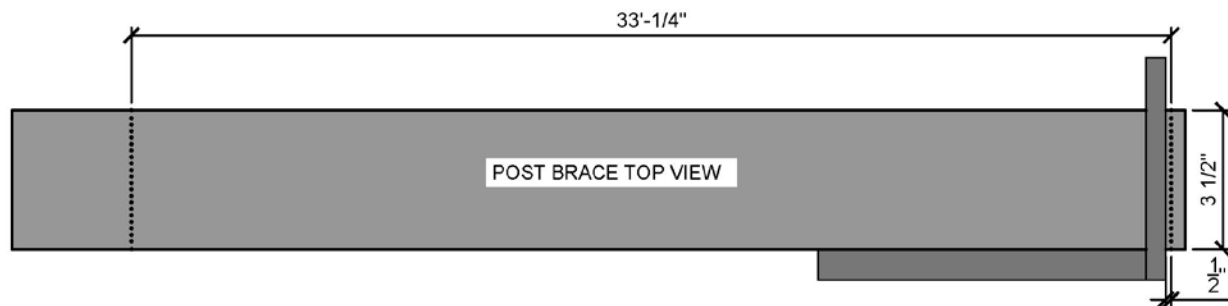
Figure 16.52 - Post Brace Length Layout



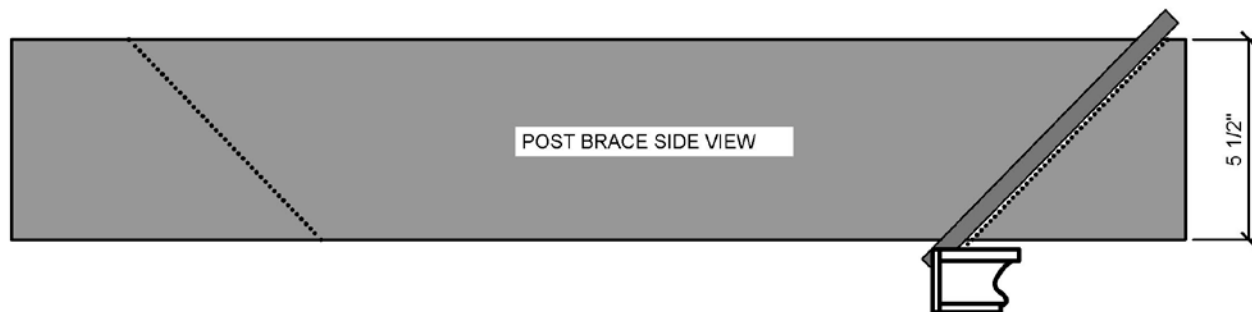
POST BRACE LENGTH LAYOUT

CALIFORNIA STATE PARKS

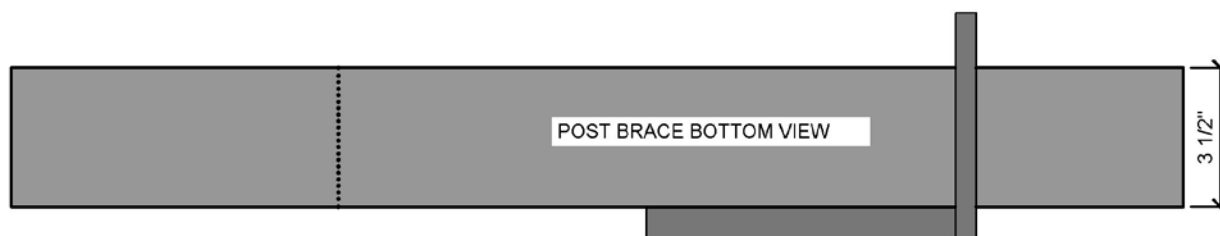
NOT TO SCALE



2. LAY THE 4"x6" BOARD WITH THE 3 1/2" SIDE UP. MEASURE IN FROM THE END OF THE BOARD 1/2" AND SCRIBE A TOP TO BOTTOM LINE ACROSS THE BOARD. THEN MEASURE 33 1/4" FROM THAT LINE TO THE OTHER END OF THE BOARD AND SCRIBE ANOTHER TOP TO BOTTOM LINE.



3. FLIP THE 4"x6" POST BRACE ON ITS SIDE. THEN LAY A COMBINATION SQUARE SET AT 45 DEGREES ALONG THE BOTTOM EDGE OF THE BOARD. SLIDE IT ACROSS THE BOTTOM UNTIL THE EDGE OF THE SQUARE BLADE AND THE LINE SCRIBED ON TOP OF THE BOARD INTERSECT. THEN SCRIBE A 45 DEGREE LINE ACROSS THE BOARD. REPEAT ON THE OTHER END OF THE BOARD.



4. FLIP THE 4"x6" POST BRACE SO ITS BOTTOM IS FACING UP. THEN LAY A FRAMING SQUARE ALONG THE BOTTOM EDGE OF THE BOARD. SLIDE IT ACROSS THE BOTTOM UNTIL THE EDGE OF THE SQUARE BLADE AND THE LINE SCRIBED ACROSS THE SIDE OF THE BOARD INTERSECT. THEN SCRIBE A 90 DEGREE LINE ACROSS THE BOARD. REPEAT ON THE OTHER END OF THE BOARD.

5. FLIP THE BOARD SO THE SIDE IS FACING UP AND USE THE THREE SCRIBED LINES TO GUIDE CUTTING THE POST BRACE AT A 45 DEGREE ANGLE.

Figure 16.53 - Post Brace Length Layout Continued



POST BRACE LENGTH LAYOUT CONTINUED

CALIFORNIA STATE PARKS

NOT TO SCALE

Place the board on its side with the 45 degree angles facing up. The board is cut along the outside of all three lines leaving part of the lines as a guide to help keep the saw cut straight. For many people, this cut is difficult to perform, especially using a circular saw. A sharp hand saw often works best for crews. Check the saw cut by placing the combination square across the bottom and side of the 45 degree cut. The edge of the square should be resting against the bottom of the cut all the way across its length. If it does not, the cut was not straight and will have to be corrected using a wood rasp to remove the high areas.

The post brace is now placed into position on top of the post sill. Check the ends of the 45 degree cuts to see if they are flush against the post and post sill. Also, check if the post brace is the correct length. If the bridge stringers are plumb and the post sill and post were installed correctly, the brace should fit properly. If the post brace has good 45 degree cuts and is the proper length, it can be used as a template for the remaining post braces. If there are some minor problems with the post or post sill that prevent the post brace from making full contact along the 45 degree cuts, the problems can be corrected individually. It is not uncommon for each post or post sill to have some imperfections. If the post braces are identical and are all installed uniformly, the line will look even when sighted down the outside of the bridge.

The post brace is attached to the post sill and post by toe nailing with galvanized 30d nails. Drill 3/16-inch diameter pilot holes before driving in the nails. (See Figure 16.54.)

16.17. Decking

16.17.1. Decking Selection

The selection, layout, and installation of decking were covered in Chapter 15, *Timber Planking, Puncheon, and Boardwalk Structures*. One significant difference between boardwalk decking and bridge decking is the thickness of the deck boards. Deck boards for bridges should be a minimum of 3 inches thick for pedestrian bridges and 4 inches thick for equestrian bridges (boardwalk decking material is typically 2 inches thick). There are some additional characteristics that are unique to bridges described below.

16.17.2. Decking Installation

Once the decking material is selected, it is cut to the appropriate length. The decking should extend beyond the outside stringers by a minimum of 6 inches. The overhang is necessary to cover the exposed sides of the stringers for aesthetic purposes. It also ensures that the decking extends beyond the posts and railings and prevents trail users from stepping off the end of the decking when walking next to the railing.

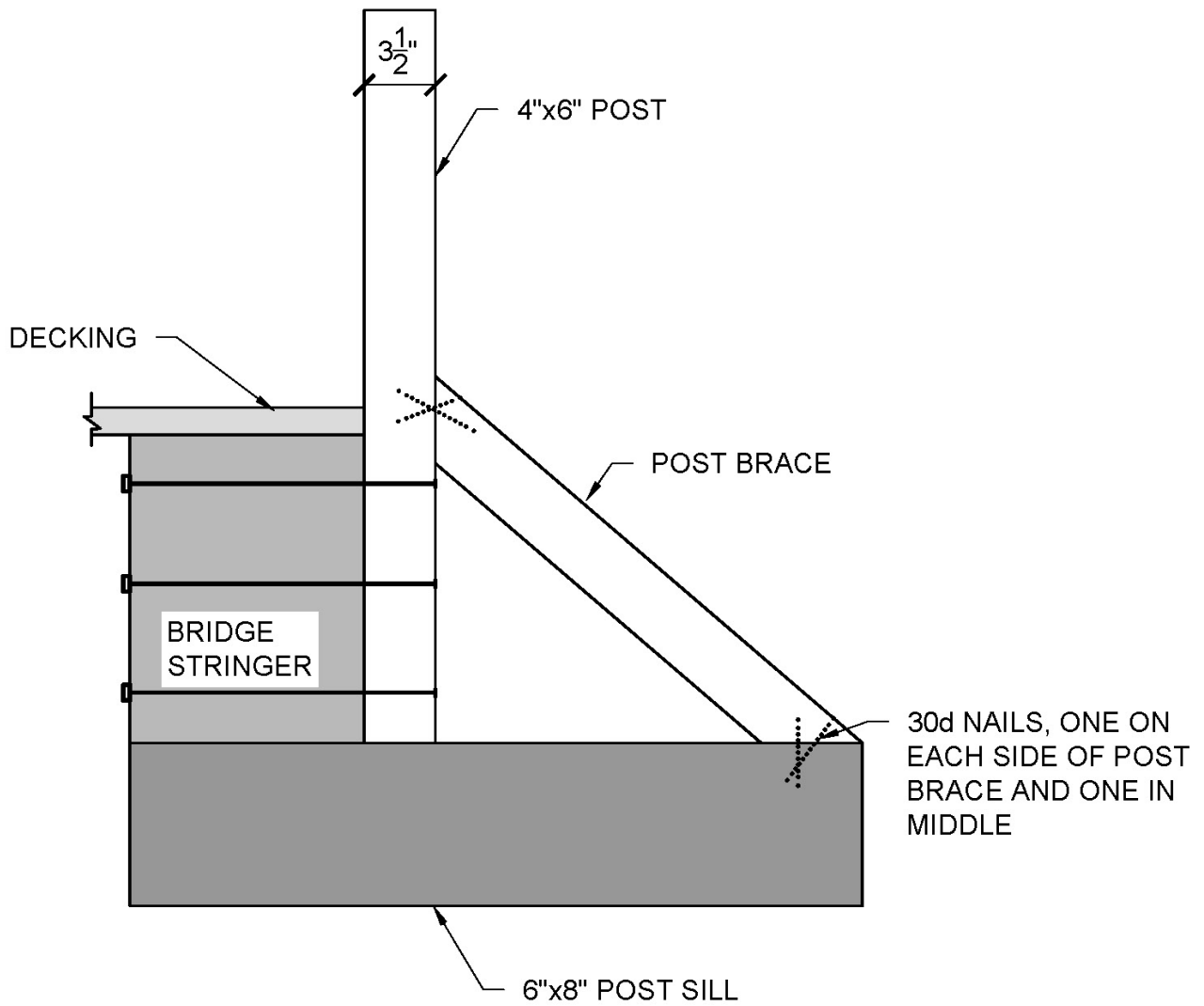


Figure 16.54 - Post Brace Attachment Nailing Pattern



POST BRACE ATTACHMENT NAILING PATTERN

CALIFORNIA STATE PARKS

NOT TO SCALE

The decking can be cut at the shop and carried to the job site, or carried to the job site and cut to length there. This decision is often influenced by packing logistics, but faster and more precise cuts are obtained using a radial arm saw or a cut-off saw at the shop. If using pressure treated lumber, it is best to order the decking lumber in the required lengths so the ends of the boards are pressure treated. If pressure treated lumber is cut, the wood preservative is compromised. It will not last as long even if the cut ends are painted with a wood preservative.

Next, begin placing the decking on the bridge stringers. Note, on some all-weather steel I beam, aluminum truss, and fiber reinforced plastic I beam bridge designs, a 4- x 6-inch nailer will be attached to the top of the stringers. (See Appendix I, *Bridge Plans*, for details on installing nailers to these types of bridges.) The decking boards should be laid with the crown side up to help prevent the sides of the board from warping upward (cupping) in the future. The decking should be laid perpendicular to the direction of the stringers. As each piece of decking is laid down, it is centered on the stringers by measuring the length of the overhang on each end. This task is performed more efficiently by two people than one. The overhang should be the same on both ends of the decking board. If it is not, the decking must be adjusted by moving the decking board toward the shorter overhang side. (See Figure 16.55.) Once a decking board is centered on the stringers, the next piece of decking is laid down next to it. The same process is followed except a gap is left between the two pieces of decking to allow for future swelling and shrinkage. Normally, a 1/4-inch gap is sufficient, but some materials and climates may require 3/8 inch or more. A wooden wedge, piece of steel, or a 1/4-inch bolt can be placed between the two pieces of decking to maintain a uniform gap. In cool, wet climates where the decking never dries out, no gap between the decking boards is required. In these climates, the gaps will accumulate organic material, which may increase rot in the decking and stringers. In a very hot and dry desert climate, board shrinkage can be substantial. In these conditions, decking should be installed without a gap, otherwise the gap may become too wide especially by accessible trail standards.

A rough or irregular edge to the decking will reduce the uniform appearance of the structure causing it to blend more with the natural environment. This edge can be accomplished by off-setting the overhang of the decking. For example, a decking board with a 7-inch overhang on one side may have a 5-inch overhang on the other side. When the next board is laid down the overhang is reversed to provide the irregular edge. (See Figure 16.56.)

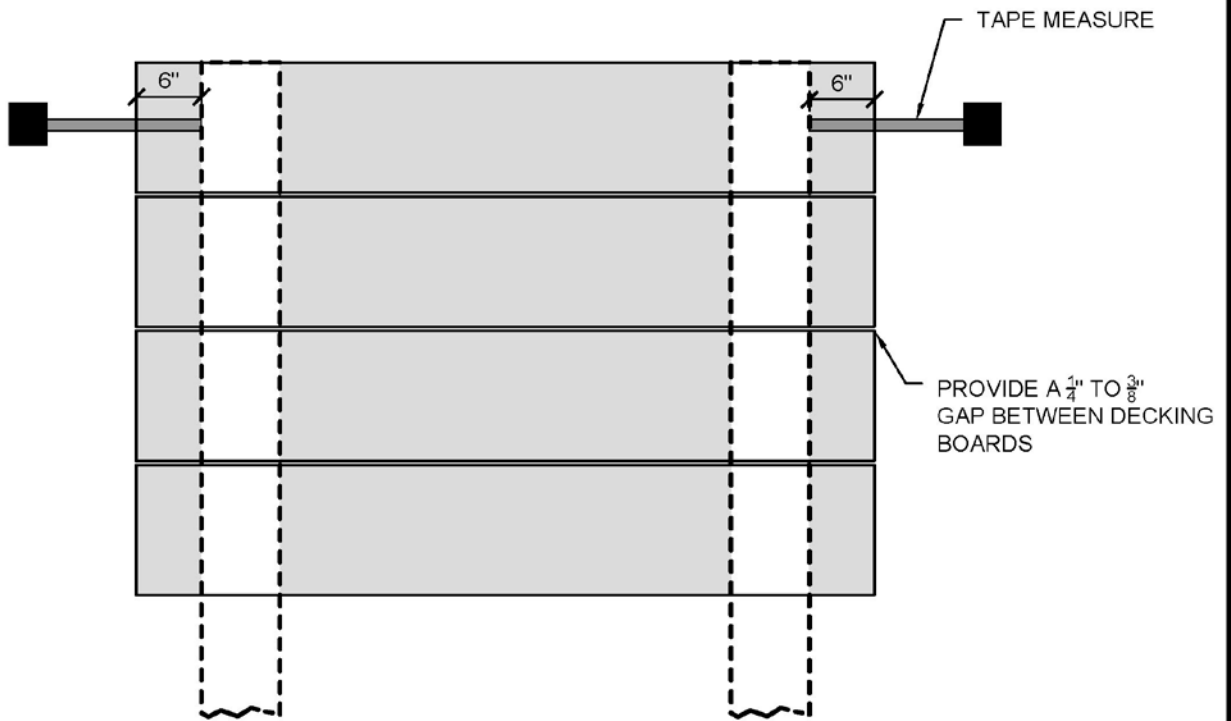
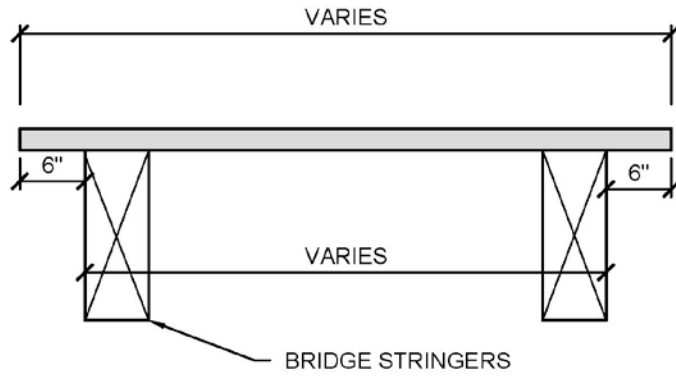


Figure 16.55 - Bridge Deck Layout Without Stagger



BRIDGE DECK LAYOUT WITHOUT STAGGER

CALIFORNIA STATE PARKS

NOT TO SCALE

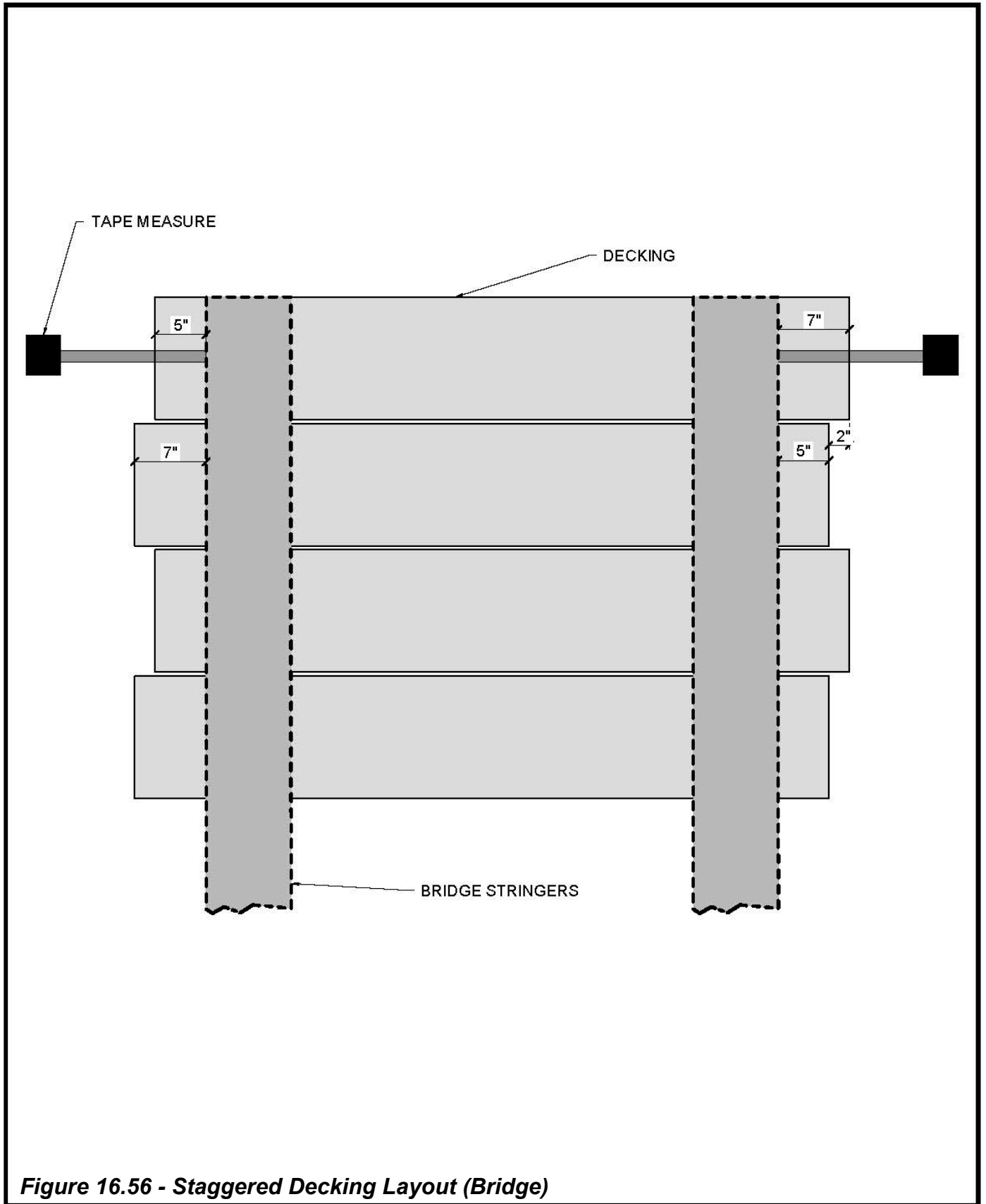


Figure 16.56 - Staggered Decking Layout (Bridge)



STAGGERED DECKING LAYOUT (BRIDGE)

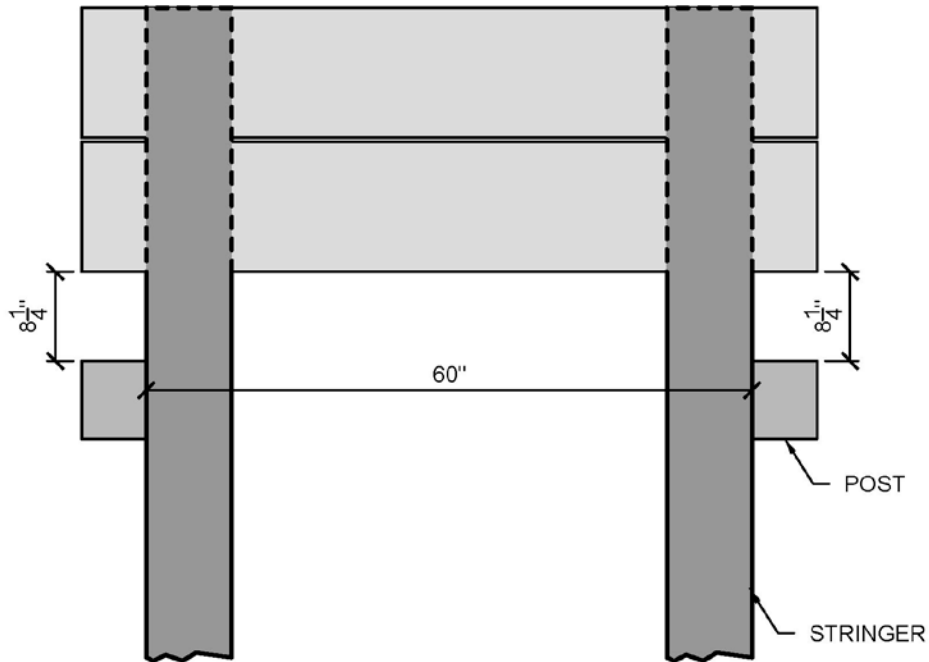
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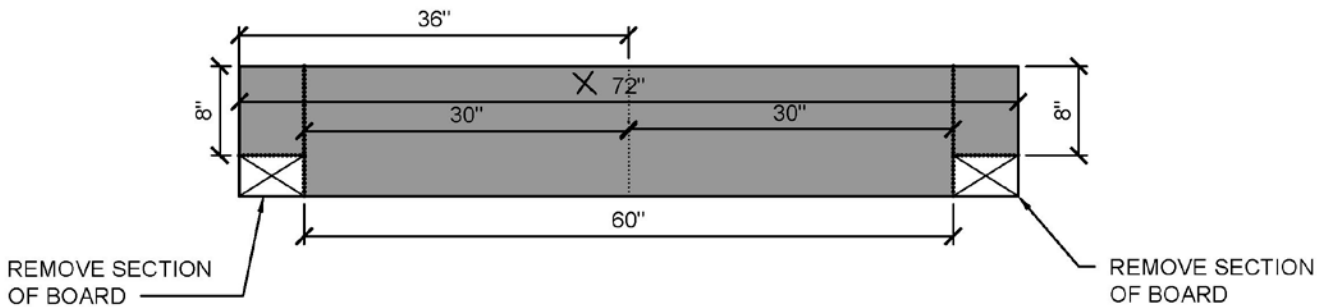
Decking will need to be notched to fit around the posts. Make a simple sketch of the decking and record all the measurements on the sketch. The layout for notching is performed by first measuring the distance between the two posts, from one side of the bridge to the other side, which is 60 inches in this example. (See Figure 16.57). Write down that measurement. Next, measure the distance from the edge of the last piece of decking laid to the post, which is 8 1/4 inches in this example. This measurement should be taken on both ends of the decking since the measurement to each post may not be the same. If this decking board does not extend past the post, no further measurement is required. (See Figure 16.57.)

Once these measurements are taken, lay the next decking board flat on two saw horses or any stable and relatively level surface. Mark an "X" on the side of the decking that will butt up to the previously laid decking. The "X" is necessary to help maintain the correct orientation of the board as it is being laid out, cut, and installed. Find the center of the decking board by measuring the length and dividing it in half. Measure that distance from one end of the decking and scribe a line across the center of the board using a framing square. (See Figure 16.57.) Divide the previously measured distance between the posts (60 inches) in half and measure that distance (i.e., 30 inches) in both directions from the center line and scribe lines using a framing square. These lines represent where the decking will be cut to fit inside the posts. (See Figure 16.57.)

Next, subtract 1/4 inch from the measurements between the last decking laid and the post (e.g., 8 1/4 in. - 1/4 in. = 8 in.) to provide a gap between the last decking board and the one being notched. Note, if a larger gap is required (e.g., 3/8 inches), subtract that measurement. If no gap is required, use the 8 1/4-inch measurement. Then, measure 8 inches from the top edge of the decking board (side with the "X" on it) down the outside edge of the board and scribe a mark at that location. With the use of a framing square, scribe a line from the 8-inch mark to the line marking the inside of the post. If the decking board does not extend beyond the posts then use a pencil to mark the area within the two lines with an "X". The "X" denotes the portion of the board to be removed from the decking board so it fits around the post. (See Figure 16.57) After the layout is complete, use a cross cut hand saw to cut along the two lines to remove the wood representing the notch. Repeat this measurement, scribing, and cutting process on the other end of the board.



MEASURE THE DISTANCE BETWEEN THE POSTS (60"). THEN MEASURE FROM THE EDGE OF THE DECKING JUST INSTALLED TO THE INSIDE OF THE POSTS. SUBTRACT $\frac{1}{2}$ " FROM THIS MEASUREMENT IF A GAP BETWEEN THE DECKING BOARDS IS REQUIRED. RECORD THESE MEASUREMENTS FOR USE WHEN PERFORMING THE NOTCHING LAYOUT ON THE DECK BOARD.



MARK AN X ON THE SIDE OF THE BOARD THAT WILL BUTT UP AGAINST THE PREVIOUSLY LAID DECKING. MEASURE THE LENGTH OF DECKING (72") AND DIVIDE THAT NUMBER IN HALF (36"). THEN MEASURE IN FROM ONE END OF DECKING 36" AND SCRIBE A CENTER LINE FROM THE TOP OF THE BOARD TO THE BOTTOM. FROM THE CENTER LINE MEASURE OUTWARDS HALF THE DISTANCE BETWEEN THE POST (30") IN BOTH DIRECTIONS AND SCRIBE LINES FROM THE TOP OF THE BOARD TO THE BOTTOM. THESE TWO LINES IDENTIFY THE INSIDE OF THE POSTS. THEN MEASURE FROM THE TOP OF THE BOARD (MARKED WITH AN X) 8" AND SCRIBE PERPENDICULAR LINES FROM THE ENDS OF THE BOARD TO THE LINES MARKING THE INSIDE OF THE POSTS. MARK AN "X" ACROSS THE AREAS ON THE BOTTOM OUTSIDE CORNERS AS THE WOOD INSIDE THOSE LINES WILL BE REMOVED FOR THE NOTCH.

Figure 16.57 - Notching Decking Around Post (Partial Notch) Bridge



NOTCHING DECKING AROUND POST (PARTIAL NOTCH) BRIDGE

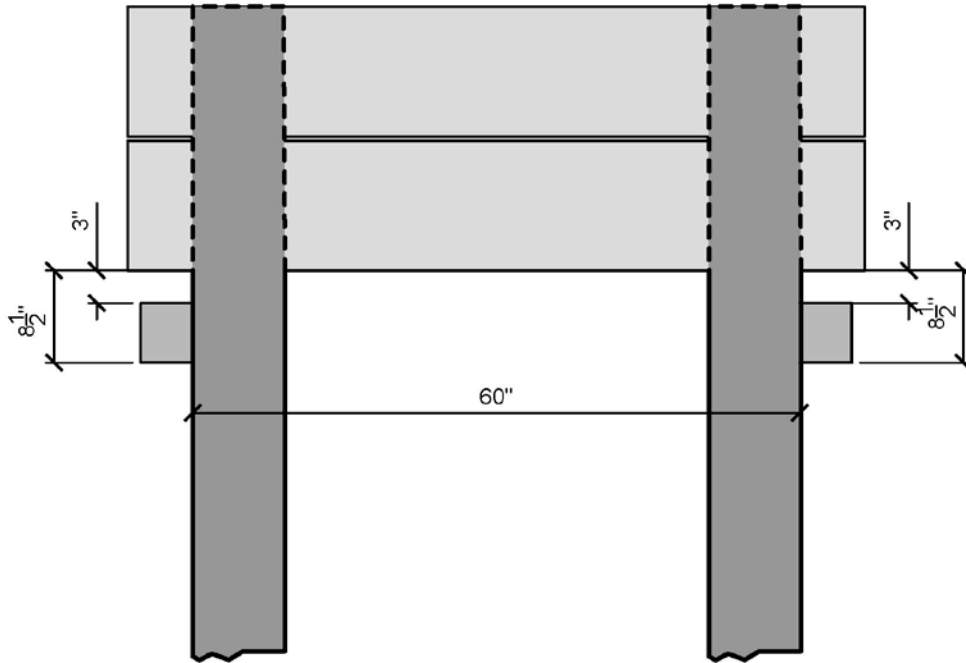
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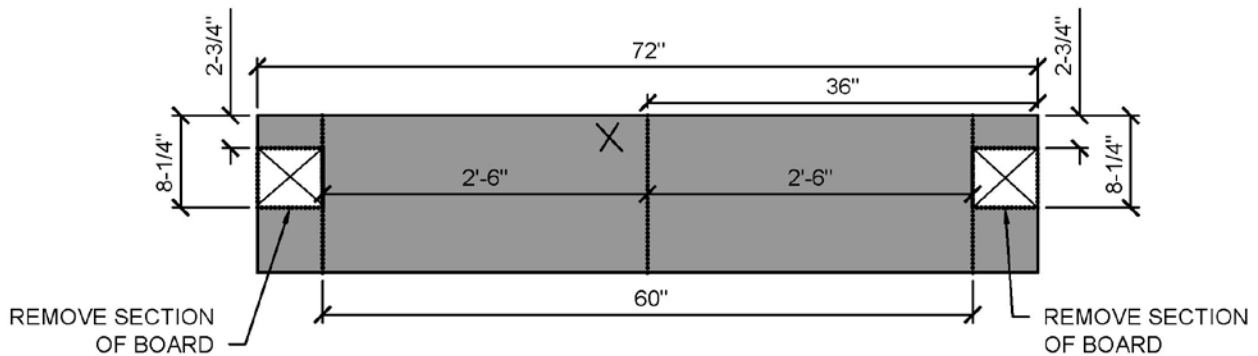
If a full notch is required, perform the measurements for delineating the inside of the post as previously discussed, then measure from the edge of the last decking board to the closest and furthest edges of the post. (See Figure 16.58.) Again, subtract the designed width of the gap between the decking boards (e.g., 1/4 inch) from both of these measurements. Then, measure from the top edge of the decking board (side with the “X” on it) down the outside edge of the board and scribe marks at those two measurements. With the use of a framing square, scribe lines from these two marks to the line marking the inside of the post. Repeat this measurement and scribing process on the other end of the board. Mark the area within the three lines with an “X” for removal. (See Figure 16.58.) Remove this notch by drilling a hole with a 3/4-inch auger drill bit in each inside corner of the notch. A cross cut hand saw can then be used to cut along the two parallel lines and a keyhole saw can be used to cut along the perpendicular line to remove the notch.

When placing the decking, it is important to periodically measure from the end of the bridge where the decking installation began to where the last piece of decking was placed. This measurement should be made inside the posts along both sides of the decking. If one measurement is longer than the other, the decking boards on the short side need to be spaced further apart until the two measurements are the same. (See Figure 16.59.) In this manner, the decking is maintained square to the structure and won't have to be tapered at the end of the bridge. Different measurements can result from not maintaining the same gap on each end of the boards or not having the structure square prior to installing the decking. It can also occur when using rough sawn boards since their dimensions can vary by as much as 1/16 inch per board. If the structure is not square, the adjustment will have to be made along the full length of the decking; otherwise the last decking board will be wedge-shaped. Installing a wedge-shaped board requires additional work, is visually obtrusive, and demonstrates poor craftsmanship.

Once the decking has the required gaps and is square, secure it to the stringers or nailers. If the ends of the stringers are exposed, hammer an 8d nail into the decking at the ends of the bridge and over the center of each stringer or nailer. Next, attach a chalk line to a nail on one end of the bridge and stretch it taut to a nail on the opposite end of the bridge. When the chalk line is snapped it will leave a faint line across the top of the decking boards, directly above the center of the stringers or nailers. If the bridge is less than 15 feet long, one snap usually suffices. However, with longer spans it will be necessary to hold the chalk line down with one hand and snap it with the other at 10 foot intervals along the bridge to obtain a legible chalk line. Repeat this process for each stringer or nailer.



MEASURE THE DISTANCE BETWEEN THE POSTS (60"). THEN MEASURE FROM THE EDGE OF THE DECKING JUST INSTALLED TO THE INSIDE OF EACH POST. SUBTRACT $\frac{1}{4}$ " FROM THIS MEASUREMENT IF A GAP BETWEEN THE DECKING BOARDS IS REQUIRED. THEN MEASURE FROM THE EDGE OF THE DECKING TO THE OUTSIDE OF EACH POST. SUBTRACT $\frac{1}{4}$ " FROM THIS MEASUREMENT IF A GAP BETWEEN THE DECKING BOARDS IS REQUIRED. RECORD THESE MEASUREMENTS FOR USE WHEN PERFORMING THE NOTCHING LAYOUT ON THE DECK BOARD.



MARK AN "X" ON THE SIDE OF THE BOARD THAT WILL BUTT UP AGAINST THE PREVIOUSLY LAID DECKING. MEASURE THE LENGTH OF DECKING (72") AND DIVIDE THAT NUMBER IN HALF (36"). THEN MEASURE IN FROM ONE END OF DECKING 36" AND SCRIBE A CENTER LINE FROM THE TOP OF THE BOARD TO THE BOTTOM. FROM THE CENTER LINE MEASURE OUTWARDS HALF THE DISTANCE BETWEEN THE POSTS (30") IN BOTH DIRECTIONS AND SCRIBE A LINES FROM THE TOP OF THE BOARD TO THE BOTTOM. THESE TWO LINES IDENTIFY THE INSIDE OF THE POST. THEN MEASURE FROM THE TOP OF THE BOARD (MARKED WITH AN X) 2-3/4" AND SCRIBE PERPENDICULAR LINES FROM THE END OF THE BOARD TO THE LINES MARKING THE INSIDES OF THE POSTS. THEN MEASURE FROM THE TOP OF THE BOARD 8-1/4" AND SCRIBE PERPENDICULAR LINES FROM THE END OF THE BOARD TO THE LINE MARKING THE INSIDES OF THE POSTS. MARK AN "X" ACROSS THE AREAS OUTLINED BY THESE THREE LINES AS THE WOOD INSIDE THOSE LINES WILL BE REMOVED FOR THE NOTCH.

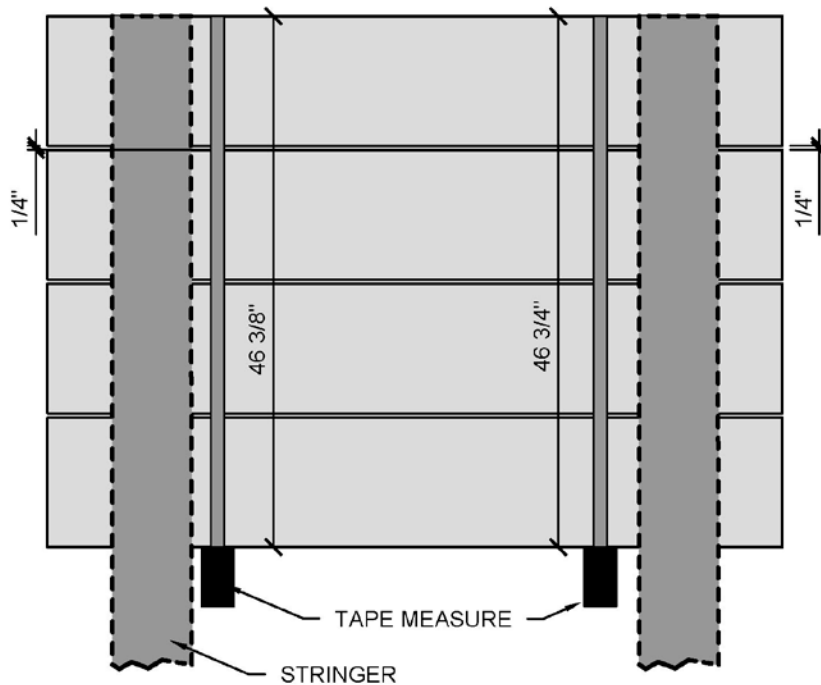
Figure 16.58 - Notching Decking Around Post (Full Notch) Bridge



NOTCHING DECKING AROUND POST (FULL NOTCH) BRIDGE

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AFTER LAYING DOWN FOUR OR FIVE BOARDS MEASURE THE DISTANCE FROM THE END OF THE BRIDGE TO THE OUTSIDE EDGE OF THE LAST BOARD LAID ON BOTH SIDES OF THE BRIDGE. THE MEASUREMENTS SHOULD BE THE SAME. IF NOT, SUBTRACT THE SHORT MEASUREMENT FROM THE LONG MEASUREMENT AND DIVIDE THAT NUMBER BY THE NUMBER OF GAPS BETWEEN THE BOARDS. EXAMPLE: $(46 \frac{3}{4} - 46 \frac{3}{8} = \frac{3}{8}) (\frac{3}{8}) / 3 \text{ GAPS} = \frac{1}{8}$. THEN INCREASE THE GAPS ON THE SHORT MEASUREMENT SIDE BY $\frac{1}{8}$. THE GAPS WILL BE $\frac{3}{8}$ ON THE SHORT SIDE AND $\frac{1}{4}$ ON THE LONG SIDE. THIS WILL CORRECT THE DECKING BOARD MEASUREMENT.

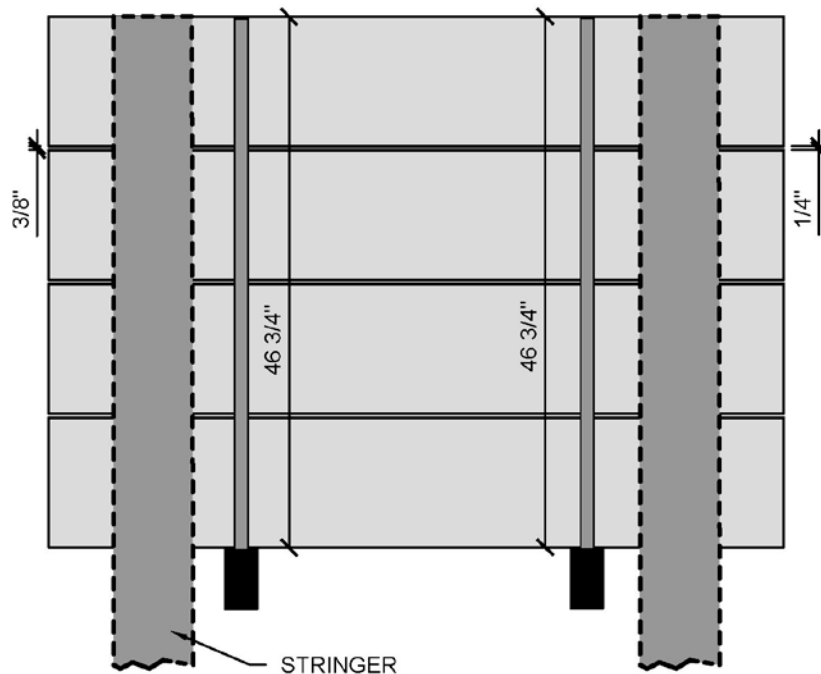


Figure 16.59 - Adjusting Deck Gap to Get it Square (Bridge



ADJUSTING DECK GAP TO GET IT SQUARE (BRIDGE)

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Once the chalk lines are in place, use a drill with a twist bit to drill pilot holes into the decking and stringer or nailer along the chalk line. Pilot holes will reduce the risk of splitting or splintering the decking boards. If the decking is 6 inches wide or less, two fasteners are used per board, placed approximately 1 1/2 inches from the edges of the boards to keep them from warping. If the boards are wider than 6 inches, three fasteners per board are used: two at approximately 1 1/2 inches from the edge of the board and one in the center. For wooden decking, the pilot holes should be one drill bit size smaller (1/32 to 1/16 in.) than the diameter of the fastener. For composite and plastic wood, the bit should be the same diameter as the fasteners because this material is very hard and deck screws would likely shear before passing through. The depth of the pilot hole should leave at least 1 1/2 to 2 inches of un-drilled wood in the joist to firmly grasp the fastener. When using long decking screws (e.g., 5 to 6 in.) it may be necessary to make the hole deeper because long screws shear easily. When the decking wood is hard and dry, it may also be necessary to lubricate the nails or screws when installing them. Liquid hand cleaner (in a can) works well for this purpose and is easy to use. Only decking screws should be used on composite lumber and plastic wood. All fasteners should be stainless steel or hot dipped galvanized steel for maximum longevity. Hot dipped galvanized nails also have a rougher surface, which enhances their grip and makes them less likely to pull loose.

For 1 1/2- to 2-inch decking, 40d nails or 5-inch decking screws should be used. For 3-inch decking, 60d or 6-inch decking screws should be used. For 4-inch decking, a 70d or 80d nails should be used.

If nails are used, they should be driven with a hammer until they are nearly flush with the deck surface. Then, a hand punch and hammer should be used to drive them approximately 1/8 inch below the surface of the deck to prevent hammer marks on the decking and eliminate tripping hazards. Deck screws should also be screwed approximately 1/8 inch below the surface of the deck.

A common practice in decking a horse bridge is to install running planks on top of the decking. (See Chapter 7, *Equestrian Trail Design*.) Given the traction problems associated with this design, thick decking installed perpendicular to the flow of traffic is preferable.

The most common method of fastening decking to a steel I beam bridge stringer is via bolt studs that are welded to the top of the I beam. The decking is laid on top of the beam at the precise location where it is to be installed. The top of the decking is lightly struck with a rawhide or rubber mallet, causing the studs to make an indentation in the decking board. Using the indentation as a guide, a hole is drilled in the decking board. Once drilled, the decking slips over the bolt stud and is anchored using a washer and nut. The finished elevation of the nut is below the top of the decking. Sometimes a sealant or caulking is spread over the recessed nut. This method of attaching the decking has numerous problems. Although the bolt stud is covered with a protective board when shipped, it can be easily bent or broken

off during transport and placement. Aligning the decking hole with the stud is difficult. The stud does not have the same life span as the bridge stringers, and when the decking is due for replacement, the stud may no longer be useable. Welding a new stud to the stringers in the field is a difficult task.

A good alternative is to have the steel I beam stringers designed and fabricated with a wooden nailer bolted to the top of the stringers. With a 4- x 6-inch board of redwood, cedar, or pressure treated Douglas fir bolted to the top of the stringers, the decking can be attached to the nailer with a 60d galvanized nail or 6-inch stainless steel deck screw. By the time the decking needs replacement, the old nailer can be removed and a new one bolted onto the stringer. This method improves the handling of the stringers, the installation of the decking, and the replacement of the decking.

When decking is installed on fiber reinforced plastic stringers, it can be attached to a 4- x 6-inch nailer or attached with carriage bolts. The stringers can be ordered to have pre-drilled holes to accept the bolts or the bolt holes can be drilled on-site. If the decking is attached to a nailer, it is installed in the same fashion as described above. If the decking boards are to be bolted directly to the stringers, they are laid on top of the stringers at the precise locations where they are to be installed. The decking is clamped to the stringers with pipe or C-clamps. Using the holes in the stringers as guides, the bolt holes in the decking are drilled. Carriage bolts are then inserted through the decking and stringers. Washers and nuts are slipped over the ends of the bolts and tightened with a socket and ratchet wrench. The heads of the bolts should be slightly below the decking surface when complete.

16.18. Soil Dam

Once the decking has been fastened down, the soil dams are installed. Soil dams have two functions: (1) they prevent soil and organics from coming into contact with the stringers and decking; and (2) they support the fill material installed against the end of the bridge when the approaching trail tread is brought level to the bridge's decking. Soil dam materials should be con heart redwood, cedar, pressure treated Douglas fir, or plastic lumber. It is recommended that plastic wood be used when installing a soil dam on a bridge using non-wood stringers since it will have a similar lifespan.

The soil dam boards should be a minimum of 3 inches thick and the same length as the mudsills. The number of boards will be dictated by the overall height of the bridge. The soil dam should span from the bottom of the mudsill to the top of the decking. It is fastened to the ends of the stringers and mudsill (if using wood stringers) and the ends of the nailers and mudsill (if using non-wood stringers).

With milled wood or glulam stringers, the soil dam is installed following the process previously discussed for puncheons in Chapter 15, *Timber Planking, Puncheon, and Boardwalk Structures*. Although the process is the same, the soil dams and mudsills on a bridge are much larger than on a puncheon. Mudsills can be comprised of wood,

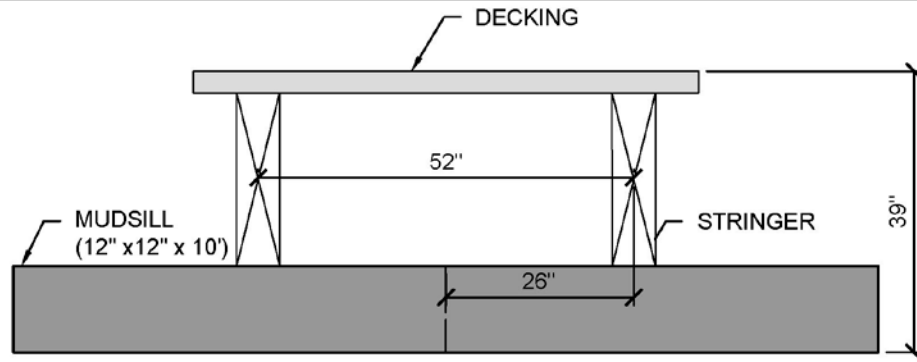
plastic wood, or concrete, requiring varying fastening techniques. A detailed layout and installation process for wooden stringer soil dams is identified in Figure 16.60.

To determine the fastening layout of non-wood stringer soil dams, first transcribe the center line from the top of the mudsill to the back of the mudsill (i.e., the side facing the end of bridge). Then measure the distance between the centers of the nailers. (See Figure 16.61.) In this example, the distance is 46 inches. Then, divide that measurement in half (23 in.) to locate the vertical center of the nailers. To determine the number of soil dam boards required, measure the distance from the top of the decking to the bottom of the mudsill (43 in.). Divide that distance by the width of the soil dam board ($43 \text{ in.} \div 12 \text{ in.} = 3.6 \text{ boards}$). Convert the 0.6 board into inches ($0.6 \text{ board} \times 12 \text{ in. per board} = 7.2 \text{ in.}$) and rip a soil dam board to that width. Measure from the top of the decking to the center of the nailer (i.e., 5 in.) and record that distance. This distance represents the horizontal center of the nailer.

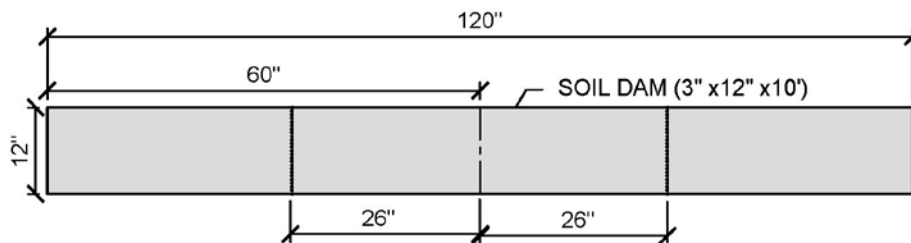
To find the center of the soil dam boards, measure the length of the soil dam board (should be the same as the mudsill, e.g., 120 in.); divide that measurement in half (e.g., 60 in.); and measure that distance (e.g., 60 in.) from the end of the soil dam board toward the center. Scribe a vertical line across the board at that distance to mark the center of the board. To identify the vertical center of the nailers, measure outward half the distance between the nailers (e.g., 23 in.) from the soil dam center line. Scribe a vertical line across the soil dam board at that distance. Continue that scribed line across the top of the top soil dam board. This line represents the vertical center of the nailer. From the top soil dam board, measure down along the vertical nailer center line to the horizontal center of the nailer (i.e., 5 inches). This location represents the horizontal center of the nailer. Mark the location where the horizontal center of the nailer and the vertical center line intersect with a horizontal line that extends 3 inches beyond both sides of the vertical center line. This line is necessary to locate this intersection once the 2- x 4-inch cleats are attached to the soil dam boards. Repeat this layout on the other nailer center line.

To assemble the soil dam, lay the soil dam boards on a flat surface, butt them together, and unitize them by bolting two 2- x 4- x 43-inch cleats to the four boards using 3/8- x 6-inch galvanized carriage bolts (two per board no closer than 1 1/2 inches from the edges of the boards). Using the line across the top of the top soil dam board and horizontal line marking the intersection of the horizontal center and vertical center lines of the soil dam boards, transcribe the vertical and horizontal lines marking the center of the nailer across the 2- x 4-inch cleat. Attach the soil dam boards to the ends of the bridge using 3/8- x 6-inch galvanized lag screws (one in each nailer and four in the mudsill). Install the lag screws per the instructions identified for decking installation above. Note, if the mudsill is concrete, use 1- x 6-inch galvanized concrete sleeve anchors to attach the soil dam to the mudsill. (See Figure 16.61).

Once the soil dams are installed, the area between the soil dams and the existing trail tread should be filled with the prescribed tread material and compacted in maximum 3-inch lifts. The finished trail grade should be flush with the top of the bridge decking.

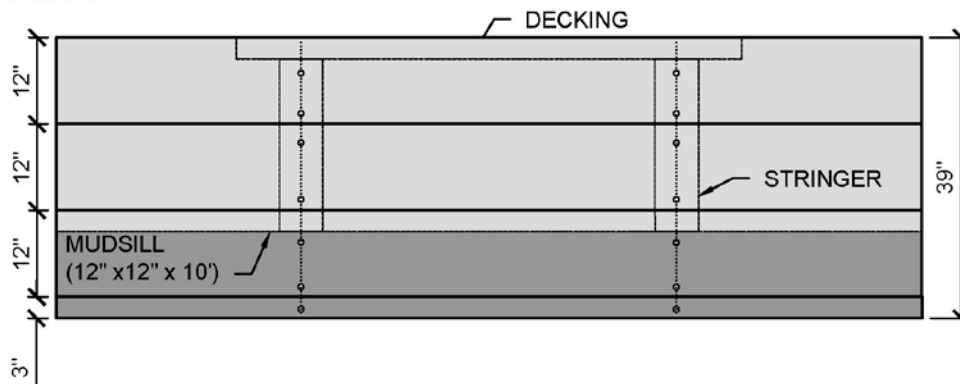


1. TRANSCRIBE THE MUDSILL CENTER LINE FROM THE TOP OF THE MUDSILL TO THE BACK OF THE MUD SILL. MEASURE THE DISTANCE BETWEEN THE CENTERS OF THE STRINGERS (52"). THEN DIVIDE THAT MEASUREMENT IN HALF (26"). MEASURE THE DISTANCE FROM THE TOP OF THE DECKING TO THE BOTTOM OF THE MUDSILL (39"). DIVIDE 39" BY THE WIDTH OF SOIL DAM BOARDS 12" ($39/12 = 3.25$ SOIL DAM BOARDS). CONVERT .25 INTO INCHES BY MULTIPLYING 12 BY .25 ($12 \times .25 = 3$ INCHES). THE SOIL DAM WILL REQUIRE THREE 12" BOARDS AND ONE 3" BOARD.



2. MEASURE THE LENGTH OF THE SOIL DAM BOARD (SHOULD BE THE SAME AS THE MUDSILL 120"). DIVIDE THAT MEASUREMENT IN HALF (60"). THEN MEASURE FROM THE END OF THE SOIL DAM BOARD TOWARDS THE CENTER THAT DISTANCE (60"). SCRIBE A VERTICAL LINE ACROSS THE SOIL DAM BOARD AT THAT DISTANCE. THIS IS THE CENTER OF THE SOIL DAM BOARD.

3. MEASURE OUTWARDS FROM THE SOIL DAM CENTER LINE HALF THE DISTANCE BETWEEN THE CENTER OF THE STRINGERS OR 26". SCRIBE VERTICAL LINES ACROSS THE SOIL DAM BOARD AT THAT DISTANCE. THESE LINES REPRESENT THE VERTICAL CENTER OF THE STRINGERS.



4. ATTACH SOIL DAM BOARDS TO END OF BRIDGE STRINGER AND MUDSILL USING 60D GALVANIZED NAILS (TWO PER BOARD EXCEPT BOARDS NARROWER THAN 6").

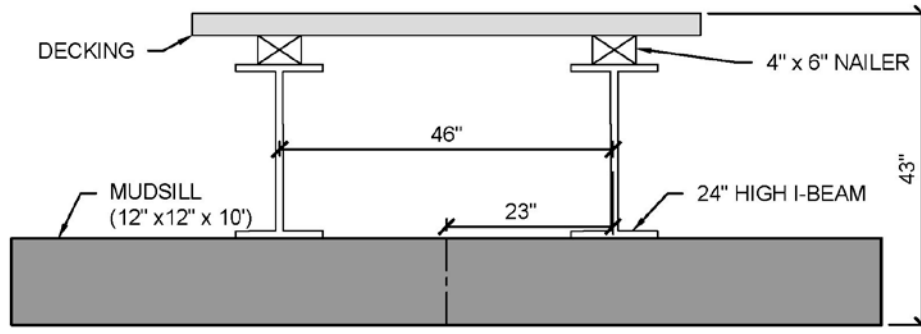
Figure 16.60 - Installing Soil Dam (Bridge)



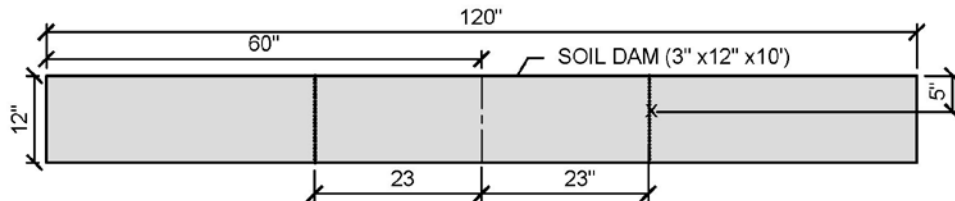
INSTALLING SOIL DAM (BRIDGE)

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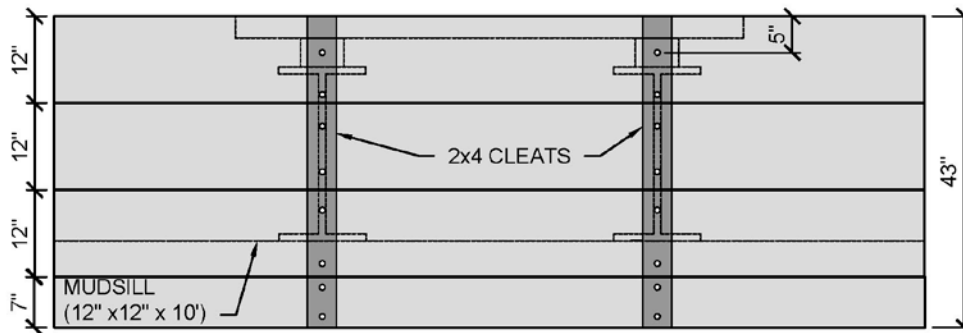


1. TRANSCRIBE THE MUDSILL CENTER LINE FROM THE TOP OF THE MUDSILL TO THE BACK OF THE MUDSILL. MEASURE THE DISTANCE BETWEEN THE CENTERS OF THE NAILERS (46"). THEN DIVIDE THAT MEASUREMENT IN HALF (23"). MEASURE THE DISTANCE FROM THE TOP OF THE DECKING TO THE BOTTOM OF THE MUDSILL (43"). DIVIDE 43" BY THE WIDTH OF SOIL DAM BOARDS 12" ($43/12 = 3.6$ SOIL DAM BOARDS). CONVERT 0.6 INTO INCHES BY MULTIPLYING 12 BY 0.6 ($12 \times .6 = 7$ INCHES). THE SOIL DAM WILL REQUIRE THREE 12" BOARDS AND ONE 7" BOARD.



2. MEASURE THE LENGTH OF THE SOIL DAM BOARD (SHOULD BE THE SAME AS THE MUD SILL 120"). DIVIDE THAT MEASUREMENT IN HALF (60"). THEN MEASURE FROM THE END OF THE SOIL DAM BOARD TOWARDS THE CENTER THAT DISTANCE (60"). SCRIBE A VERTICAL LINE ACROSS THE SOIL DAM AT THAT DISTANCE. THIS IS THE CENTER OF THE SOIL DAM BOARD.

3. MEASURE OUTWARDS FROM THE SOIL DAM BOARD CENTER LINE HALF THE DISTANCE BETWEEN THE CENTER OF THE NAILERS OR 23". SCRIBE VERTICAL LINES ACROSS THE FRONT OF ALL SOIL DAM BOARDS AND THE TOP OF THE TOP SOIL DAM BOARD AT THIS DISTANCE. THESE LINES REPRESENT THE VERTICAL CENTER OF THE NAILERS. FROM THE TOP SOIL DAM BOARD MEASURE DOWN ALONG THE NAILER CENTER LINE 5". THIS LOCATION IS THE HORIZONTAL CENTER OF THE NAILER. MARK THIS LOCATION WITH A HORIZONTAL LINE THAT EXTENDS 3" EITHER SIDE OF THE VERTICAL CENTER LINE. REPEAT LAYOUT ON OTHER NAILER CENTER LINE.



4. LAY SOIL DAM BOARDS ON A FLAT SURFACE, BUTT TOGETHER AND CONNECT BY BOLTING TWO 2" X 4" X 43" CLEATS TO THE FOUR BOARDS USING 3/8" X 6" GALVANIZED CARRIAGE BOLTS

5. LOCATE THE THE CENTER OF THE NAILER USING THE VERTICAL CENTER LINE PREVIOUSLY MARKED ON THE TOP OF THE TOP SOIL DAM BOARD AND THE HORIZONTAL CENTER LINE PREVIOUSLY MARKED 3" EITHER SIDE OF THE VERTICAL CENTER LINE. ATTACH SOIL DAM BOARDS TO END OF BRIDGE USING 3/8" X 6" GALVANIZED LAG SCREWS (ONE IN EACH NAILER AND FOUR IN THE MUDSILL). NOTE IF THE SILL IS CONCRETE USE 1/2" X 6" GALVANIZED CONCRETE SLEEVE ANCHORS TO ATTACH THE SOIL DAM TO THE SILL.

Figure 16.61 - Installing Soil Dam (Bridge Non-Wood Stringer)



INSTALLING SOIL DAM (BRIDGE NON-WOOD STRINGER)

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16.19. Railings

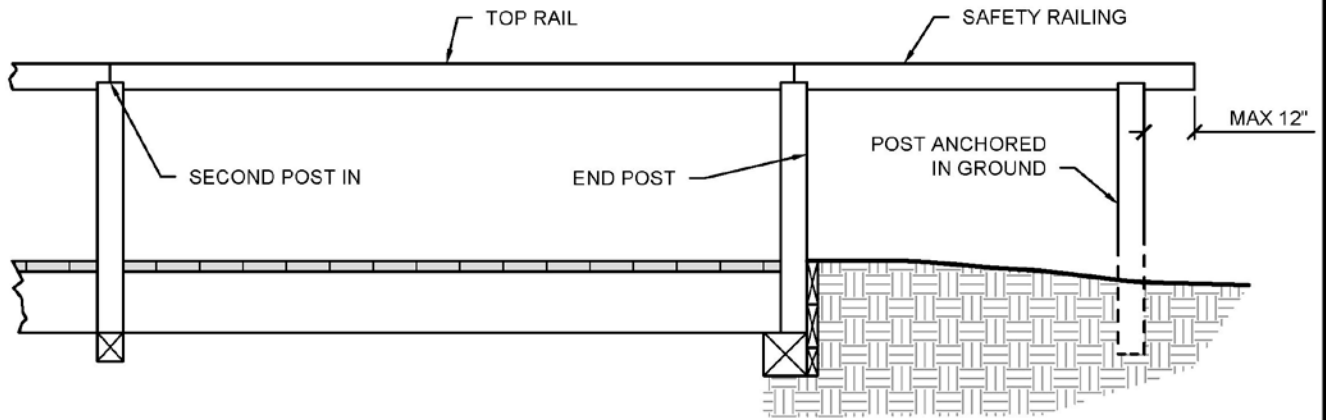
The first railing to be installed is the top, which is fastened to the top of the posts previously installed. The finished height of the railing is determined by the user group. The process for determining the correct post height was previously discussed. The railing should be 4- x 6-inch redwood or cedar. Prior to installing the first railing, determine if the railing will terminate at the end of the bridge (on the end post) or continue to a post installed in the ground beyond the bridge (a safety railing that defines the approach to the bridge). If the top railing is to terminate on the end post, it should not extend beyond the post more than 12 inches to eliminate potential breakage and provide a more aesthetically pleasing appearance. This information is necessary to determine how the top railing will be notched and secured to the post at the end of the bridge.

If a safety railing will extend to a post anchored in the ground on the approach to the bridge, the top rail is laid halfway across the top of the last post on the bridge and halfway across the second post in. The safety rail spanning from the last post on the bridge to the post anchored in the ground is laid halfway across the top of the last post on the bridge and terminates on the post anchored in the ground (not to extend more than 12 inches beyond the post). If the top rail at the end of the bridge will terminate on the last post on the bridge it is laid halfway across the second post in and terminates on the end post (not to extend more than 12 inches beyond the post). (See Figure 16.62.)

The railing should be resting flush on top of the two posts so that the outside edges of the posts and railing are directly in line with each other. If the end cuts on the railing are not square, re-cut them before proceeding. If the railing is too long and extends beyond the center of the second post, it must be cut. While the railing is lying on the post, identify the halfway point on the post and scribe a line on the railing where it intersects the halfway point. Use a carpenter's pencil and a framing square, speed square, or combination square to scribe a line across the railing that identifies where the railing is to be cut. Once that line has been scribed, use a square to scribe a second line down the edge of the railing at a right angle to the first line, resulting in two lines to cut along - one on top of the railing and one on the side of the rail.

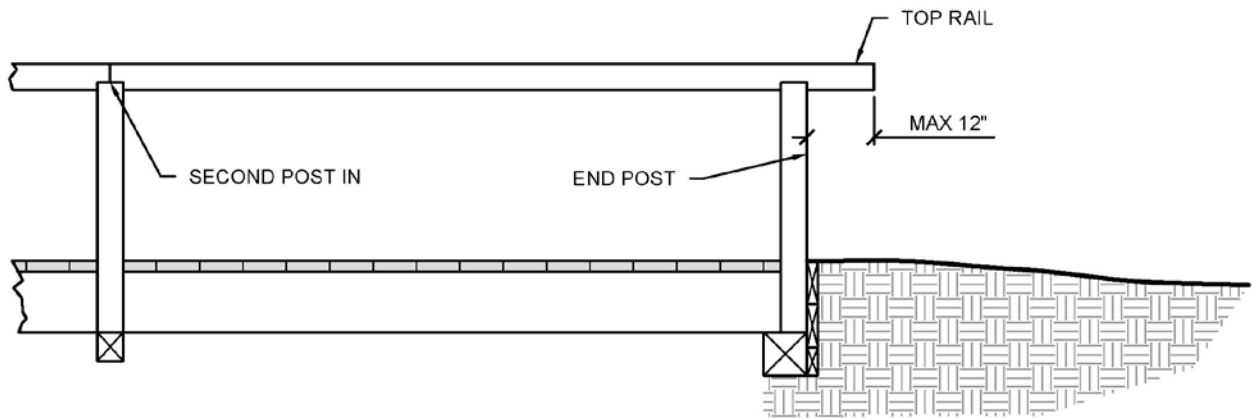
Two saw horses should be set up on or near the bridge to provide a good surface to perform the cutting and notching. Using a cross cut hand saw, cut the railing to the proper length. Place the railing back on the two posts so that it is half way across both of them.

WITH APPROACHING SAFETY RAIL



THE TOP RAIL ENDS HALFWAY ONTO THE END POST. A SAFETY RAIL BUTTS UP TO THE TOP RAIL AND TERMINATES ON A POST ANCHORED INTO THE GROUND. THE NEXT TOP RAIL BUTTS UP AGAINST ADJACENT TOP RAIL AND TERMINATES HALFWAY ONTO THE NEXT POST ON THE BRIDGE.

WITHOUT APPROACHING SAFETY RAIL



THE TOP RAIL TERMINATES ON THE END POST. IT EXTENDS BEYOND THE END POST SO THE END OF THE RAILING IS EQUAL TO OR LONGER THAN THE BRIDGE. THE NEXT TOP RAIL BUTTS UP AGAINST THE ADJACENT TOP RAIL AND TERMINATES HALFWAY ONTO THE NEXT POST ON THE BRIDGE.

Figure 16.62 - End Top Rail Installation (Bridge)



END TOP RAIL INSTALLATION(BRIDGE)

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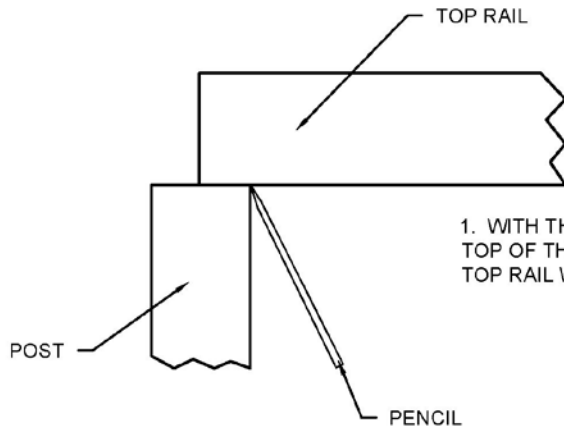
NOT TO SCALE

Once the railing is sitting flush and directly over the post, use a carpenter's pencil to scribe a line under the railing along the inside of the two posts. This line represents the inside of the railing notch. Turn the railing upside down and lay the tongue (small end) of a framing square so that it is flush with the bottom of the railing. Line the handle (large end) of the square so that it is in line with the line just scribed. Then, use a carpenter's pencil to scribe a line along the tongue of the square toward the end of the railing. Then, scribe a line along the outside of the handle to where it intersects with the line on the bottom of the railing. Perform this task on both sides of the railing. These lines represent the depth of the notch (1 1/2 in.). The tongue of a framing square is 1 1/2 inches wide so it provides the correct depth for the notches. Next, lay the framing square across the end of the railing so that the top of the tongue is flush with the bottom of the railing. The bottom of the tongue should now intersect the two lines just scribed. Scribe a line with a pencil to help maintain a square and plumb cut when notching the railing. (See Figure 16.63.) Perform this task on both ends of the railing.

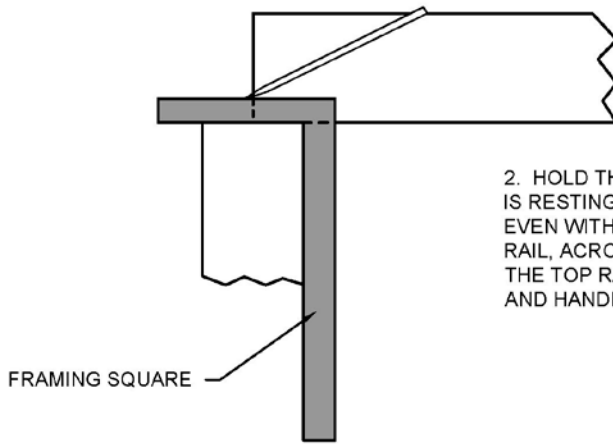
Make the first cut where the first line was scribed on the bottom of the rail. Use this line and the two depth lines on the sides to keep the cut plumb and square. Cut just inside these lines so a portion of the pencil line remains. Once this cut is complete, turn the railing on its side and cut along the two lines marking the depth of the notch. Again, keep the saw blade just inside both lines to maintain a plumb cut. Rip the board along these two lines until the cuts intersect the first cut. Once these two cuts meet, the wood in the notch can be removed. (See Figure 16.64.) Perform these same cuts on the other end of the railing.

When the notching is complete, set the railing back on top of the posts. If the scribing and cutting were performed properly, the railing should rest flush on top of both posts and the notches along the sides of the railing should fit tightly to the posts (i.e., within the thickness of a credit card). Do not make the notches too tight because there is a risk of pushing the posts apart and forcing them out of plumb. If, for some reason, the notches do not fit correctly, use a rasp or wood chisel to correct the problem. Remember, wood can always be removed but can never put it back, so be cautious when making these adjustments.

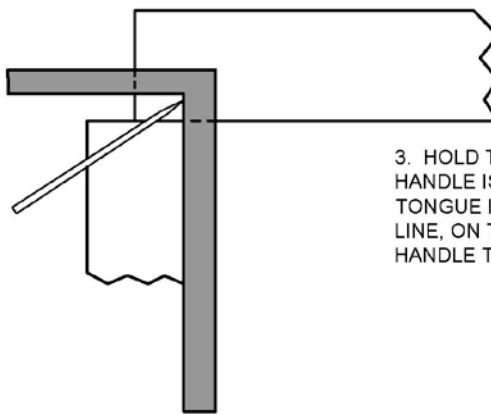
If the railing is to terminate at the end of the bridge, the notching process is altered. Instead of laying the railing halfway across the end post, it is laid so that approximately 1 foot of the railing projects beyond the post. When scribing the bottom of the railing, it is scribed on both sides of the post. The depth notches are performed in the same fashion as previously described except the notch is the full width of the post. The scribe across the end of the railing is not required because the notch is removed approximately 12 inches from the end of the railing. (See Figure 16.65.) The scribing and notching of the railing around the second post is unchanged.



1. WITH THE TOP RAIL SITTING HALFWAY ON THE TOP OF THE POST SCRIBE A LINE UNDERNEATH THE TOP RAIL WHERE IT INTERSECTS WITH THE POST.



2. HOLD THE FRAMING SQUARE SO THE INSIDE OF THE HANDLE IS RESTING AGAINST THE POST AND INSIDE OF THE TONGUE IS EVEN WITH THE TOP OF THE POST. SCRIBE A LINE, ON THE TOP RAIL, ACROSS THE TOP OF THE TONGUE FROM THE END OF THE TOP RAIL TO THE INSIDE INTERSECTION OF THE TONGUE AND HANDLE OF THE SQUARE.



3. HOLD THE FRAMING SQUARE SO THE INSIDE OF THE HANDLE IS RESTING AGAINST THE POST AND INSIDE OF THE TONGUE IS EVEN WITH THE LINE JUST SCRIBED. SCRIBE A LINE, ON THE TOP RAIL, DOWN THE INSIDE OF THE SQUARE'S HANDLE TO THE TOP OF THE POST

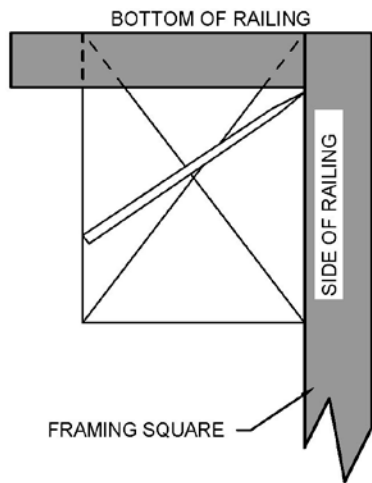
Figure 16.63 - Scribing Top Rail Notches (Partial Notch) Bridge



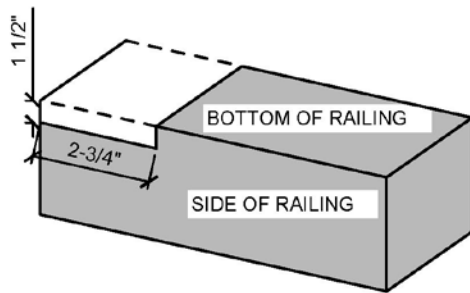
SCRIBING TOP RAIL NOTCHES (PARTIAL NOTCH) (BRIDGE)

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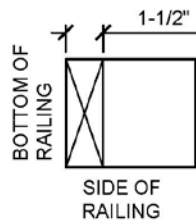
NOT TO SCALE



1. WHILE THE RAILING IS UPSIDE DOWN HOLD THE FRAMING SQUARE ALONG THE END FACE OF THE RAILING SO THE INSIDE OF THE HANDLE IS RESTING AGAINST THE SIDE OF THE RAIL AND THE OUTSIDE OF THE TONGUE IS EVEN WITH THE BOTTOM OF THE RAIL. SCRIBE A LINE DOWN THE INSIDE OF THE SQUARE'S TONGUE TO THE INTERSECTION OF THE SQUARE'S HANDLE.



2. LAY THE RAILING SO THE BOTTOM IS FACING UP. SAW VERTICALLY INSIDE OF SCRIBED LINE DOWN TO HORIZONTAL LINE ($1\frac{1}{2}$ "). USE THE LINES ON TOP AND SIDES OF THE RAIL TO KEEP SAW CUTS PLUMB. USE HORIZONTAL LINES ON THE SIDES OF THE RAILING TO CONTROL DEPTH OF CUT.



3. LAY THE RAILING ON ITS SIDE SO THE LINE SCRIBED ON THE END OF THE RAIL IS VERTICAL. SAW VERTICALLY INSIDE OF SCRIBED LINE (X) DOWN TO HORIZONTAL LINE ($2\frac{3}{4}$ "). USE THE LINES ON SIDES OF THE RAIL TO KEEP SAW CUTS PLUMB. USE HORIZONTAL LINES ON THE SIDES OF THE RAILING TO CONTROL DEPTH OF CUT.

4. REMOVE PARTIAL NOTCH

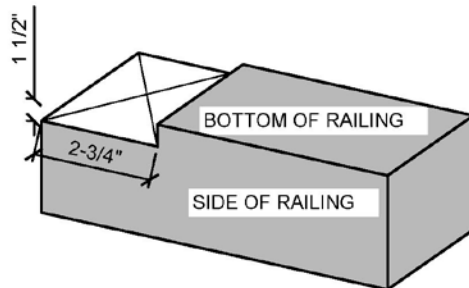


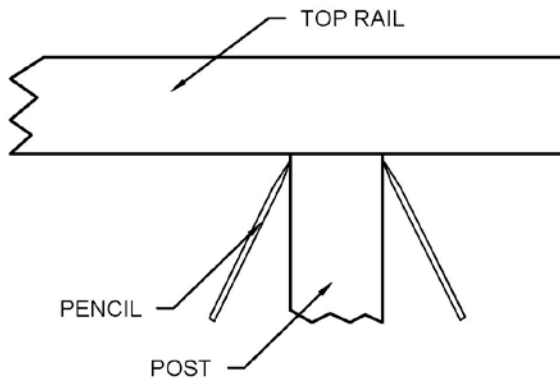
Figure 16.64 - Scribing Notch and Cutting Out the Notch (Partial Notch) Bridge



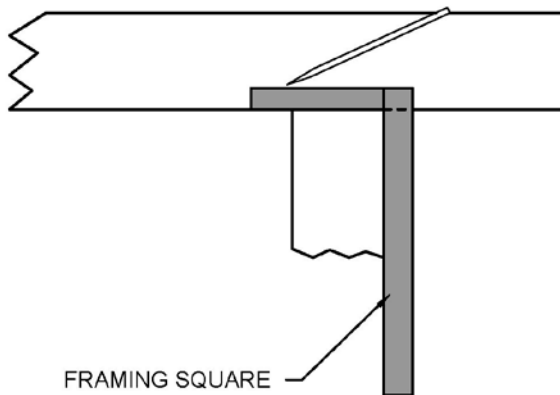
SCRIBING NOTCH & CUTTING OUT THE NOTCH (PARTIAL NOTCH) (BR.)

CALIFORNIA STATE PARKS

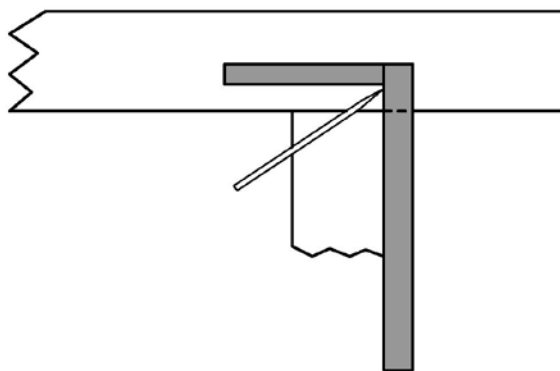
NOT TO SCALE



1. WITH THE TOP RAIL SPANNING APPROXIMATELY 1' PAST THE END POST, SCRIBE TWO LINES UNDERNEATH THE TOP RAIL WHERE IT INTERSECTS WITH THE POST..



2. HOLD THE FRAMING SQUARE SO THE INSIDE OF THE HANDLE IS RESTING AGAINST THE POST AND INSIDE OF THE TONGUE IS EVEN WITH THE TOP OF THE POST. SCRIBE A LINE, ON THE TOP RAIL, ACROSS THE TOP OF THE TONGUE FROM THE INTERSECTION OF THE POST AND RAIL TO THE INSIDE INTERSECTION OF THE TONGUE AND HANDLE OF THE SQUARE..



3. HOLD THE FRAMING SQUARE SO THE INSIDE OF THE HANDLE IS RESTING AGAINST THE POST AND INSIDE OF THE TONGUE IS EVEN WITH THE LINE JUST SCRIBED. SCRIBE A LINE, ON THE TOP RAIL, DOWN THE INSIDE OF THE SQUARE'S HANDLE TO THE INTERSECTION OF THE RAIL AND POST. REPEAT ON THE OTHER SIDE OF THE POST.

Figure 16.65 - Scribing Top Rail Notches (Full Notch) Bridge



SCRIBING TOP RAIL NOTCHES (FULL NOTCH) (BRIDGE)

CALIFORNIA STATE PARKS

NOT TO SCALE

When removing the notch that will accept the end post, perform the cut across the bottom of the railing at both scribed locations, using the lines on the top and sides to keep the cut plumb and square. Use the depth lines to control the depth of the cut. Next, make additional saw cuts between the two notch cuts. These cuts should be approximately 3/8- to 1/2-inch apart and should be as deep as the two outside notch cuts. Again, use the 1 1/2-inch lines marked on both sides of the railing to monitor the depth of the saw cuts. (See Figure 16.66.) Once the saw cuts are complete, a wood chisel or straight claw hammer is used to snap off the thin pieces of wood between the saw cuts. A wood chisel and rasp can then be used to smooth out the bottom of the notch and achieve a uniformly flat and square notch. When complete, place the railing on the two posts. If it fits tightly as described above, it is ready to fasten to the post. If not, use a wood chisel or rasp to adjust the notch until it fits properly.

The railing is fastened to the post using galvanized 40d nails. Pilot holes are drilled through the railing and posts to reduce splitting. The twist bit for the pilot holes should be 1/32- to 1/16-inch less than the shank of the fastener. The fasteners are driven in at an angle to provide better attachment to the post and reduce splitting. (See Figure 16.67.) The head of the nails are set flush with a drift punch. Note, because of the steep angle, setting the nails too deeply will likely result in splitting the railing.

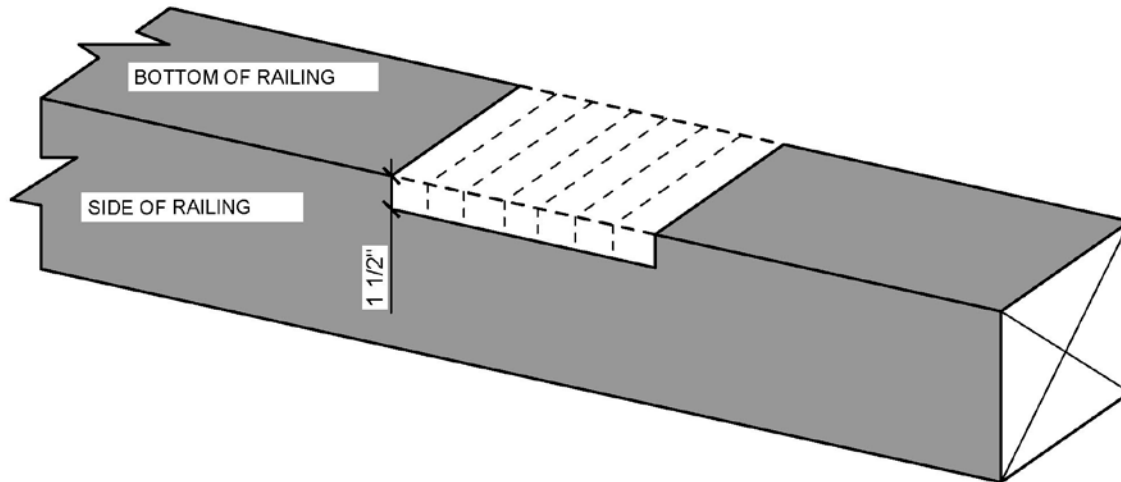
Once the first railing is secured, the next railing is set on top of the second and third posts in the same fashion. When the railing is set on the second post, it is shoved tightly against the previously installed railing. Depending on the quality of the cuts, there may be small gaps between the ends of these two railings. If so, hold the second railing tightly, and, keeping it firmly against the end of the first railing, set a handsaw flush against the end of the second railing. This portion of the second railing is protruding 1 1/2 inches above the two railings because this railing has not been notched yet. Using the end (face) of the second railing as a guide, saw straight down between the ends of the two railings to remove the wood that was preventing the two ends of the railings from fitting tightly together. Sometimes it may take two or three cuts to accomplish the desired fit.

Once a tight fit is achieved, the second railing is scribed and cut as previously described. If another railing is needed, it will end lying halfway across the third post and the same scribing and notching procedures are applied. If it is the last railing, the end will be scribed and notched in the same fashion as the first railing.

16.20. Bull Rails

If required, bull rails are installed once the posts and top railings are assembled. They are installed as previously described in the puncheon construction section of Chapter 15, *Timber Planking, Puncheon, and Boardwalk Structures*.

1. LAY THE RAILING SO THE BOTTOM IS FACING UP. SAW VERTICALLY INSIDE OF SCRIBED LINES DOWN TO HORIZONTAL LINE ($1\frac{1}{2}$ "). USE THE LINES ON TOP AND SIDES OF THE RAIL TO KEEP SAW CUT PLUMB. USE HORIZONTAL LINES ON THE SIDES OF THE RAILING TO CONTROL DEPTH OF CUT. MAKE SAW CUTS APPROXIMATELY $\frac{3}{8}$ " APART ACROSS THE NOTCH.



2. USE A STRAIGHT CLAW HAMMER OR A WOOD CHISEL TO BREAK OUT THE WOOD BETWEEN THE SAW CUTS. THEN USE A WOOD CHISEL TO CLEAN OUT THE BOTTOM OF THE NOTCH. LEVEL AND SMOOTH THE BOTTOM OF THE NOTCH WITH A WOOD RASP.

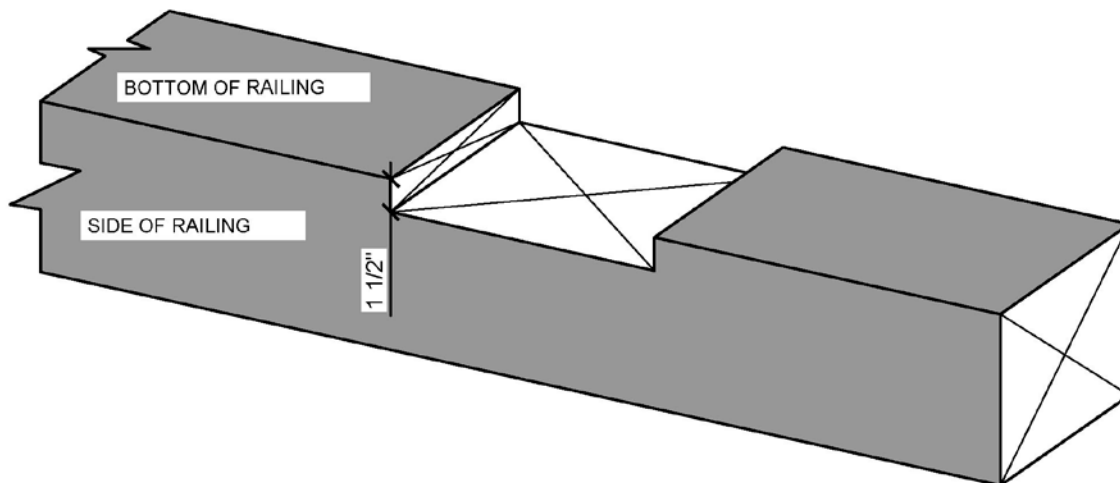


Figure 16.66 - Scribing Notch and Cutting Out the Notch (Full Notch) Bridge

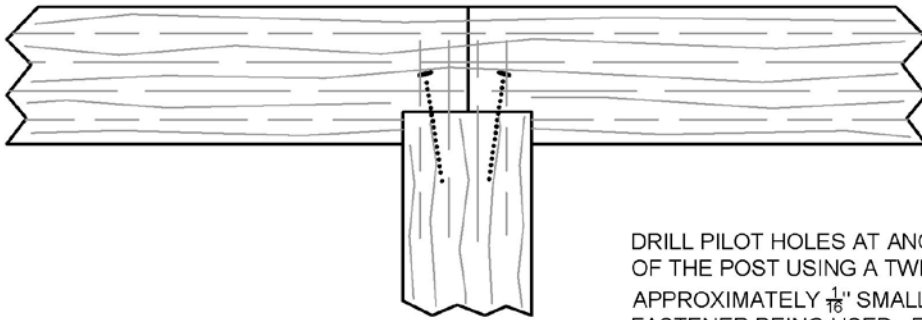


SCRIBING NOTCH & CUTTING OUT THE NOTCH (FULL NOTCH)(BR.)

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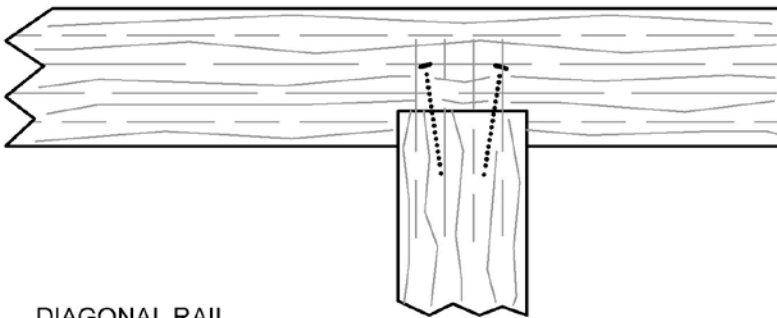
NOT TO SCALE

TOP RAIL BUTTED ON TOP OF POST



DRILL PILOT HOLES AT ANGLE TOWARDS THE CENTER OF THE POST USING A TWIST DRILL BIT APPROXIMATELY $\frac{1}{16}$ " SMALLER IN DIAMETER THAN THE FASTENER BEING USED. FASTEN RAILS TO THE POST USING 40d GALVANIZED NAILS. SET NAIL HEADS BELOW THE SURFACE OF THE RAIL USING A PUNCH.

TOP RAIL NOTCHED ON TOP OF POST



DIAGONAL RAIL

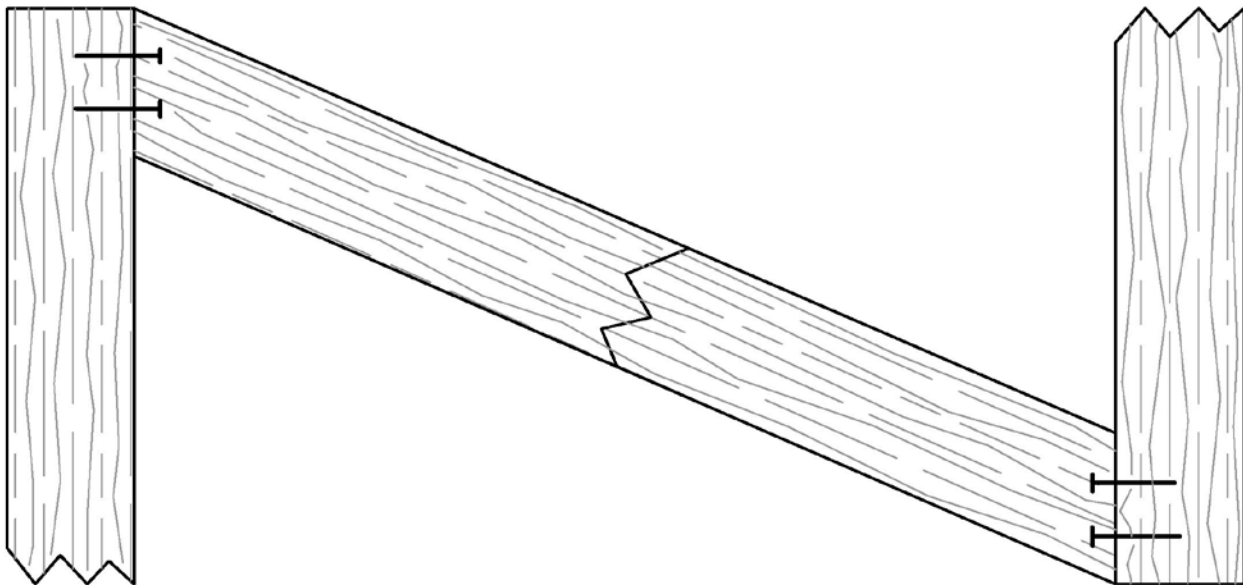


Figure 16.67 - Nailing Patterns for Handrails (Bridges)



NAILING PATTERNS FOR RAILINGS (BRIDGES)

CALIFORNIA STATE PARKS

NOT TO SCALE

16.21. Diagonal Rails

After all the posts, top railings, and bull rails (if required) are installed, the diagonal rails are installed. The diagonal rails provide an additional safety barrier under the top railing and between the posts. Generally, the diagonal rails are installed so they are angled in the same direction, however, any pattern can be applied by the trail designer. For the purposes of this discussion, the diagonal rails will be installed at the same angle and direction. Since they are installed diagonally between the posts, they need to be 1 to 2 feet longer than the top railing, depending on the prescribed finished height.

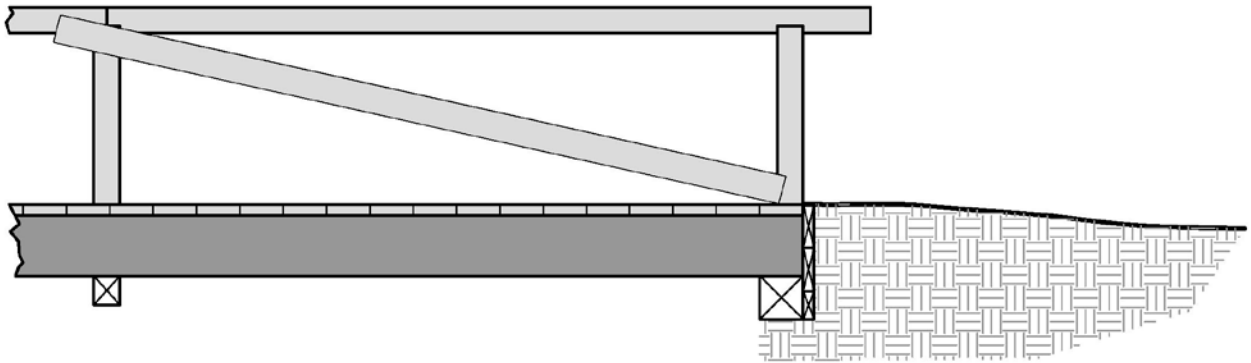
Starting at the end of the bridge, measurements for a diagonal rail are made by laying one end of the board to be used for the diagonal rail on the decking at the inside base of the first post, while the other end is held against the inside of the second post just below the intersection of the top railing. Next, the end of the diagonal rail resting on the decking is placed so the bottom corner is at the intersection of the first post and the decking. The bottom corner of the diagonal rail should be flush against the inside of the post. Then, the upper end of the diagonal rail is held so the top of the diagonal rail is at the intersection of the post and the bottom of the top rail. The inside of the diagonal rail should be flush against the inside of the post and top rail. (See Figure 16.68.)

Make sure both ends of the diagonal rail are at the proper intersections. Then, hold the diagonal rail firmly in place and use a carpenter's pencil to scribe a line at both locations where the diagonal rail and post come together. (See Figure 16.68.) These two lines are the angles the diagonal rail must be cut to fit inside the two posts. This layout and scribing is best performed by two people - one at each end of the diagonal rail. If working alone, the diagonal rail can be held in place with a wood or C-clamp while the lines are scribed. Note, if bull rails have been installed, the lower end of the diagonal rail is placed where the top of the bull rail and post intersect. (See Figure 16.69.)

After scribing these lines, set the diagonal rail on the saw horses and use a combination or framing square to scribe additional lines at right angles to the ends of the diagonal lines. The bottom end of the diagonal rail will require one additional line. This line is across the top of the railing and will serve as a visual guide when performing the diagonal cut. (See Figure 16.70.) Once the additional line is scribed, lay the rail on its side with the diagonal line facing up and the top line facing you. Use a hand saw to cut along the two pencil lines, leaving a portion of the pencil lines. Watch the top diagonal line, as well as the perpendicular line, when cutting through the rail. If cutting along both lines, the cut will be plumb and square.

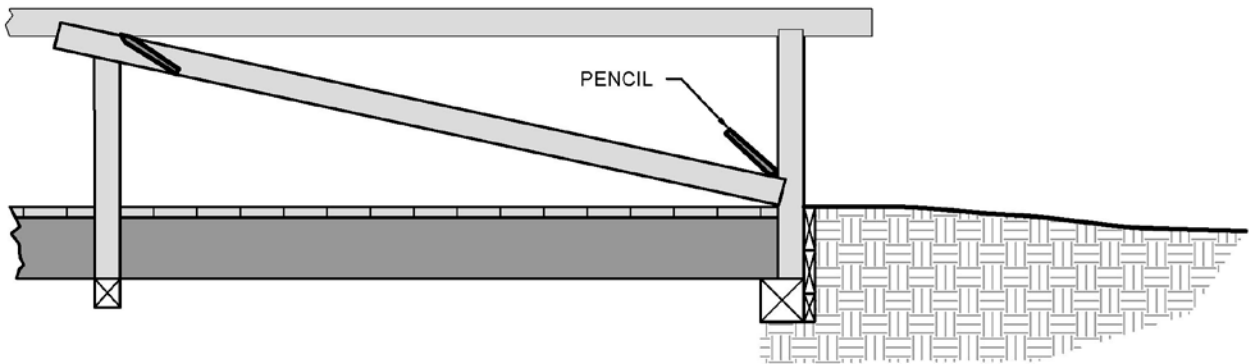
The top end of the diagonal rail will require a line on the top and bottom to serve as a visual guide when performing the diagonal cut. Once these lines are scribed, lay the rail on its side with the diagonal line facing up and the top line facing you. Use a hand saw to cut outside of the three pencil lines, leaving a portion of the pencil lines. Watch the top diagonal line, as well as the two perpendicular lines, when cutting through the rail. If cut along all three lines, the cut will be plumb and square. (See Figure 16.70.)

INSIDE OF RAILING VIEW



1. PLACE THE DIAGONAL RAILING ON THE INSIDE OF THE POST WITH THE BOTTOM EDGE OF THE RAIL RESTING ON THE DECKING. THE BOTTOM CORNER OF THE RAIL SHOULD BE FLUSH WITH THE INTERSECTION OF THE POST AND THE DECKING. THE OTHER END OF THE RAIL SHOULD BE PLACED SO THE TOP OF THE RAIL IS AT THE INTERSECTION OF THE TOP RAIL AND POST.

OUTSIDE OF RAILING VIEW



2. ONCE THE DIAGONAL RAIL IS IN THE PROPER LOCATION USE A CARPENTERS PENCIL TO SCRIBE A LINE ALONG THE OUTSIDE OF THE DIAGONAL RAIL WHERE IT INTERSECTS WITH THE POST.

Figure 16.68 - Diagonal Railing Layout (Bridge)

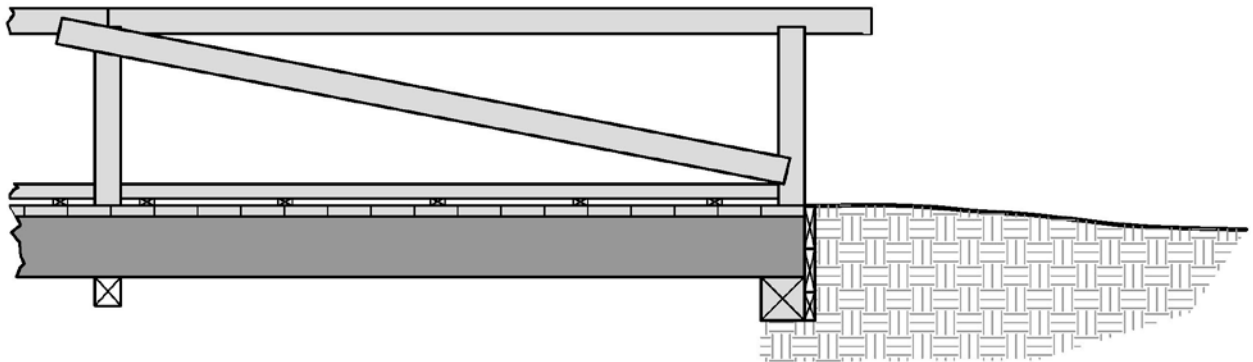


DIAGONAL RAILING LAYOUT (BRIDGE)

CALIFORNIA STATE PARKS

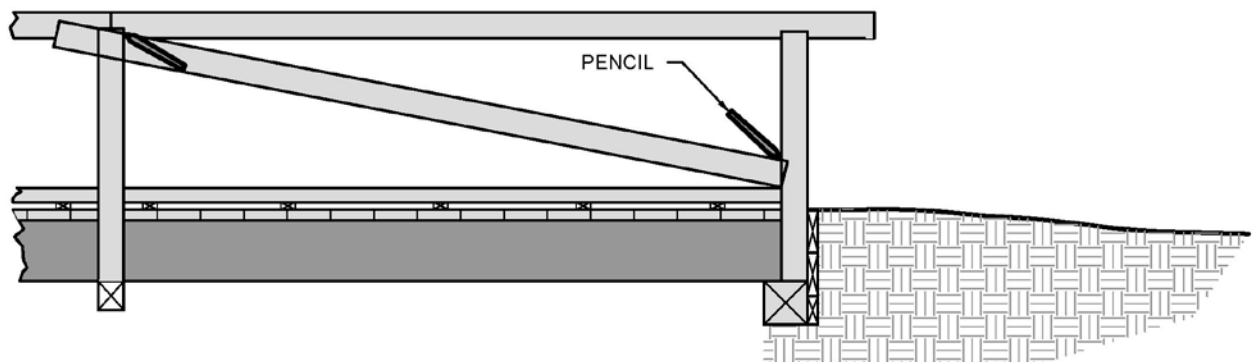
NOT TO SCALE

INSIDE OF RAILING VIEW



1. PLACE THE DIAGONAL RAILING ON THE INSIDE OF THE POST WITH THE BOTTOM EDGE OF THE RAIL ON TOP OF THE BULL RAIL. THE BOTTOM CORNER OF THE RAIL SHOULD BE FLUSH WITH THE INTERSECTION OF THE POST AND THE BULL RAIL. THE OTHER END OF THE RAIL SHOULD BE PLACED SO THE TOP OF THE RAIL IS AT THE INTERSECTION OF THE TOP RAIL AND POST.

OUTSIDE OF RAILING VIEW



2. ONCE THE DIAGONAL RAIL IS IN THE PROPER LOCATION USE A CARPENTERS PENCIL TO SCRIBE A LINE ALONG THE OUTSIDE OF THE DIAGONAL RAIL WHERE IT INTERSECTS WITH THE POST.

Figure 16.69 - Diagonal Railing Layout with Bull Rail (Bridge)

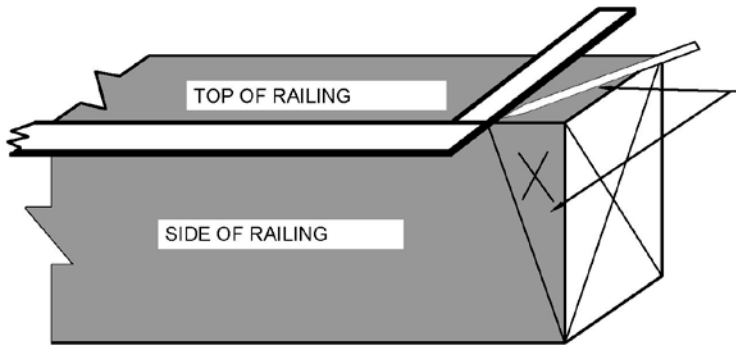


DIAGONAL RAILING LAYOUT WITH BULL RAIL (BRIDGES)

CALIFORNIA STATE PARKS

NOT TO SCALE

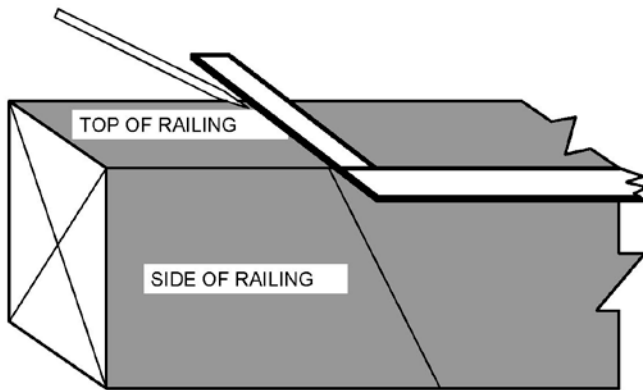
BOTTOM OF THE DIAGONAL RAIL



AREA TO BE REMOVED

FOR THE BOTTOM END OF THE DIAGONAL RAIL, SET THE RAIL SO THE TOP IS FACING UP. LOCATE THE POINT WHERE THE PREVIOUSLY SCRIBED DIAGONAL LINE ENDS AT THE TOP OF THE RAILING. FROM THIS POINT USE A COMBINATION OR FRAMING SQUARE TO SCRIBE A LINE ACROSS THE TOP OF THE RAIL. THEN LAY THE RAIL ON ITS SIDE WITH THE LINE ACROSS THE TOP FACING YOU. USE A HAND SAW TO CUT ALONG THE OUTSIDE OF THE TWO LINES.

TOP OF THE DIAGONAL RAIL



FOR THE TOP END OF THE DIAGONAL RAIL, SET THE RAIL SO THE TOP IS FACING UP. LOCATE THE POINT WHERE THE PREVIOUSLY SCRIBED DIAGONAL LINE ENDS AT THE TOP OF THE RAILING. FROM THIS POINT USE A COMBINATION OR FRAMING SQUARE TO SCRIBE A LINE ACROSS THE TOP OF THE RAIL. FLIP THE RAIL UPSIDE DOWN AND LOCATE THE POINT WHERE THE PREVIOUSLY SCRIBED DIAGONAL LINE ENDS AT THE BOTTOM OF THE RAILING. FROM THIS POINT SCRIBE A THIRD LINE ACROSS THE BOTTOM OF THE RAIL. THEN LAY THE RAIL ON ITS SIDE WITH THE LINE ACROSS THE TOP FACING YOU. USE A HAND SAW TO CUT ALONG THE OUTSIDE OF THE THREE LINES.

AREA TO BE REMOVED

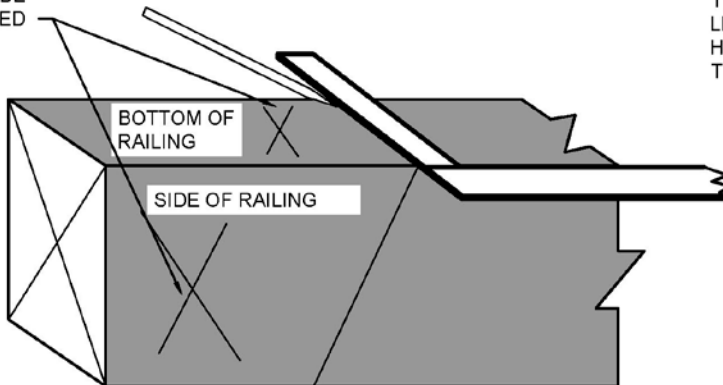


Figure 16.70 - Scribing and Cutting Diagonal Rails (Bridges)



SCRIBING AND CUTTING DIAGONAL RAILS (BRIDGES)

CALIFORNIA STATE PARKS

NOT TO SCALE

After cutting both ends, set the rail so it sits just inside of the two posts at the correct angle. Slowly slide both ends of the diagonal rail toward the outside of the post. Note that the railings are intended to fit tightly. If one end is slid in first or gets ahead of the other end, the diagonal rail will bind up between the two posts. If the diagonal rail is too tight, do not force it between the posts because it will drive the two posts apart, making them out of plumb and ruining the notching just performed. If the fit is too tight, remove the rail and look at the cut ends for signs of scuffing or wood compression. Also look at the inside of the two posts for similar marks. Then, use a pencil to outline these “high” areas on the cut ends that are causing the bind. Use a wood rasp to cut down these areas, then re-insert the diagonal rail. If it still is too tight, repeat the process until it fits. Be cautious not to remove too much wood at once because it cannot be replaced and will leave a gap in the railing joint.

Once the proper fit is achieved, the diagonal rail is fastened in the same fashion as the top rails, with two nails or screws driven in at an angle on both sides of the railing. (See Figure 16.67.) The rest of the diagonal rails are installed in the same fashion as just described.

After all the railings are installed, the posts and railings are sanded to remove splinters and rough areas that might injure a trail user. Additional finishing work, such as rounding-off all the corners with a draw knife and rasp, can also be performed to give the structure a more rustic appearance. It is important to note that what trail users most often observe when viewing a bridge are the railing and decking. Quality workmanship on these two items will greatly enhance the user’s appreciation of the bridge.

16.22. Project Logistics and Efficiency

Although the individual tasks for constructing a bridge have been discussed in a progressive fashion, it should be understood that two or more of these task could occur at the same time. For example, diaphragms, sway braces, and posts could all be installed as the crew works its way across the bridge. Similarly, post sills, posts, and post braces could all be installed at the same time. Decking, soil dams, and railings could also be installed at the same time once the decking is installed past the first set of posts. Generally, the assembly of a bridge requires only five to six workers, so when working with larger crews it is important to have additional trail work going on adjacent to the bridge site so the entire crew stays productive. Larger crews also allow the flexibility of adding crew members to the bridge assembly when tasks require more workers.

16.23. Ordering Bridge Stringers

This chapter has reviewed a variety of customized bridge designs. When purchasing customized bridge stringers from a vendor, it is important to provide the vendor with the information necessary to design and fabricate bridge components that will meet the needs of the project. Bridge components will take time to order, refine the design, and fabricate, so sufficient time should be allowed prior to bridge installation. The ordering

of customized bridge components should occur at least four to six months prior to bridge installation. Whether it is a wooden glulam or all weather steel I beam bridge, the following information should be supplied to the manufacturer.

1. Span length (overall span and free span between sills)
2. Bridge width (outside to outside measurement of stringers)
3. Beam seat design: mudsill, concrete sill, concrete beam seat
4. Basic drawing of bridge superstructure including the bridge components, dimensions, and materials (e.g. redwood 4- x 6-inch posts, redwood 4- x 6-inch railings, 3- x 12-inch pressure treated Douglas fir decking, etc.)
5. Estimated dead load of bridge (total weight of bridge superstructure)
6. Required live load of bridge (100 pounds per square foot)
7. Snow load, if applicable (obtain from local county building department)
8. Wind shear or seismic conditions, if applicable (obtain from a certified engineer)
9. Railing post layout for post drilling schedule in stringers, angle clips (fiber reinforced plastic I beam), and metal gussets (all weather steel I beam)
10. Use and dimensions of wooden nailer for all weather steel, I beam, fiber reinforced plastic I beam, and aluminum truss drilling schedule