Chapter 3: Forms

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3-1 Introduction

Concrete is a unique building material in that it may be cast into a desired shape at the building site while in the plastic state and retain that shape after hardening. Concrete is given its intended shape using forms, which must be built in such a manner that the resulting concrete member will be the correct size and shape. Forms also serve to control the alignment, elevation, and position of concrete members within the completed structure.

Formwork, also known as forms, is the system used to hold freshly placed concrete in its desired shape until it hardens - from sheathing or form panels to all supporting members, hardware, and necessary bracing. Concrete forms also render texture and surface characteristics to the concrete surface. As such, the quality of workmanship in the forming system often determines the amount of subsequent work needed to achieve the required surface finish.

See *Construction Manual*, Section 4-5103D, *Forms*, for a list of items to address when inspecting forms.

3-2 Specifications

Contract Specifications, Section 51-1.03C(2), *Concrete Structures – General – Construction – Preparation – Forms*, contains requirements for concrete forms, which include the structural adequacy and appearance of the finished product. The requirements for forming exposed surfaces are extensive and detailed.

3-3 Forming System

For most cast-in-place (CIP) concrete structures, the forming system will consist of a form surface material or sheathing, studs, walers, and kickers, all adequately braced to retain the concrete within the required line, grade, and dimensions. The forming system also includes forming accessories such as ties, anchors, and spreaders.

Sheathing is the forming material that is in direct contact with the concrete and is therefore the element that renders the texture and surface characteristics of the formed concrete. Plywood is by far the most common sheathing material; however, depending on the type of construction and surface finish required, form sheathing can be surfaced lumber, steel, or, in some cases, synthetic materials, such as form liners. The APA – The Engineered Wood Association’s publication, *Concrete Forming: Design/Construction Guide*, is an excellent source of technical information on plywood sheathing material and form design.

If used for forming exposed or visible surfaces, plywood must at least meet the requirements for U.S. Product Standard PS 1 for Exterior B-B (Concrete Form) Class I Plywood. Figure 3-1 shows a typical APA grade stamp on plywood.

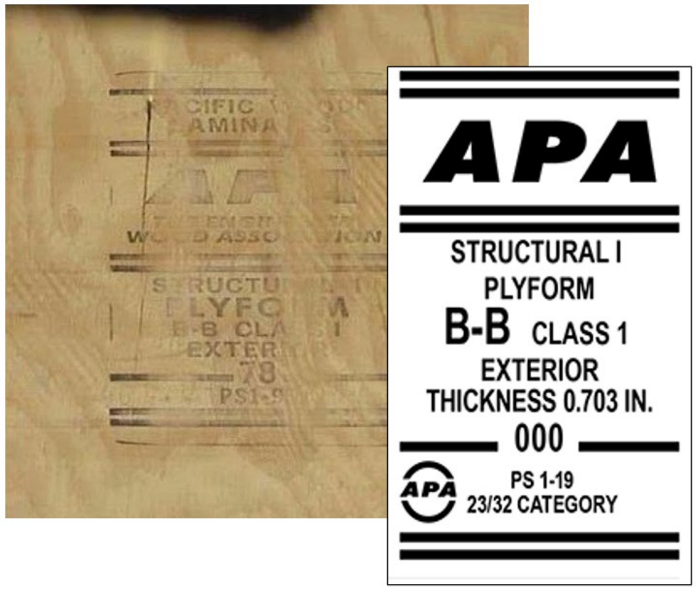

Figure 3-1. Illustration of APA PS 1 Grade Stamp

Other sheathing material may be used in forms for exposed concrete surfaces, provided it produces a smooth, uniform concrete surface substantially equal to that which would result from the use of the specified plywood, such as metal forms. Steel and polyvinyl chloride (PVC) are materials that may be acceptable for forming exterior surfaces. Increasingly, form liners are being specified as a sheathing material for exposed concrete surfaces to render architectural treatment to the formed concrete surface.

The form sheathing is reinforced by a system of studs and walers to allow it to withstand the load imposed by wet concrete. For jobsite-built plywood forms used for such custom-built bridge components and elements as abutments, retaining walls, and box girder superstructures, studs are vertical form elements, usually made of dimensional lumber, to which the sheathing is attached. Essentially, studs serve as sheathing reinforcement that allows the sheathing to confine the freshly placed concrete. The studs are spaced to limit the deflection of the sheathing between the studs. Walers are horizontal form components that support the vertical studs. Walers are usually installed in pairs against the studs, facilitating the use of concrete ties that are inserted and secured to keep the forms from separating. The actual stud and waler spacing is governed by specified deflection criteria, lateral concrete load, and allowable stresses. Figure 3-2 shows typical wall forming using studs and walers.

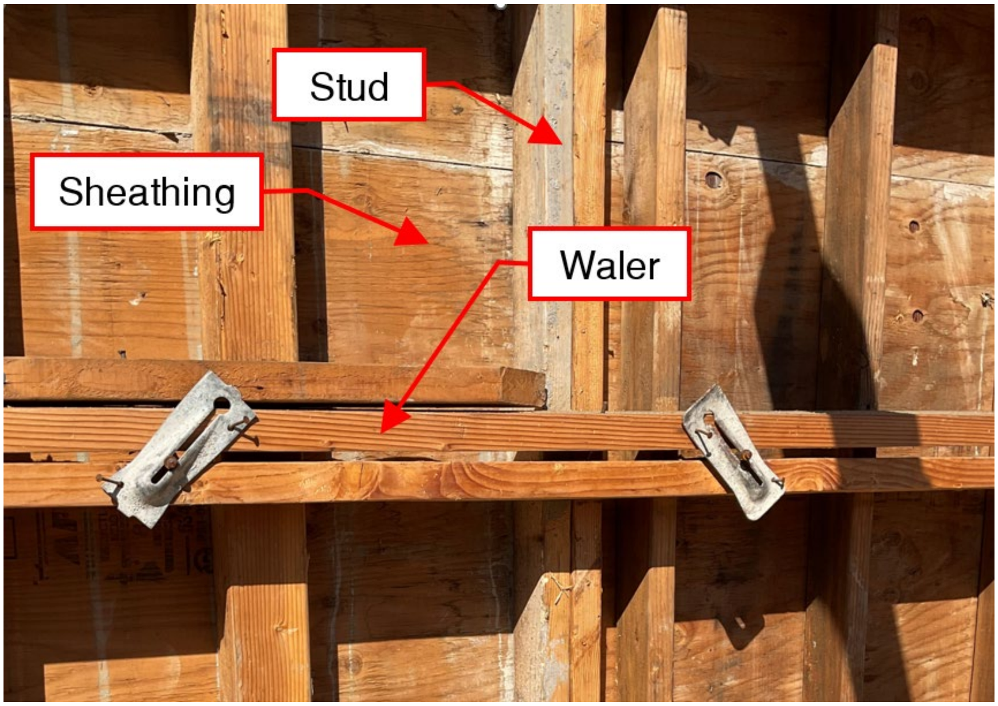

Figure 3-2. Wall Forming Using Studs and Walers

Vertical concrete forms must be braced to transfer all horizontal loads to the support and to prevent instability. Kickers are braces installed diagonally between the form and the ground or a stable platform, keeping vertical forms plumb and providing stability to the whole system. Kickers are important because if not properly braced, the forms may deflect or shift, in which case remedial work may be necessary to obtain the required lines and grades. Figure 3-3 illustrates typical forms braced with kickers.

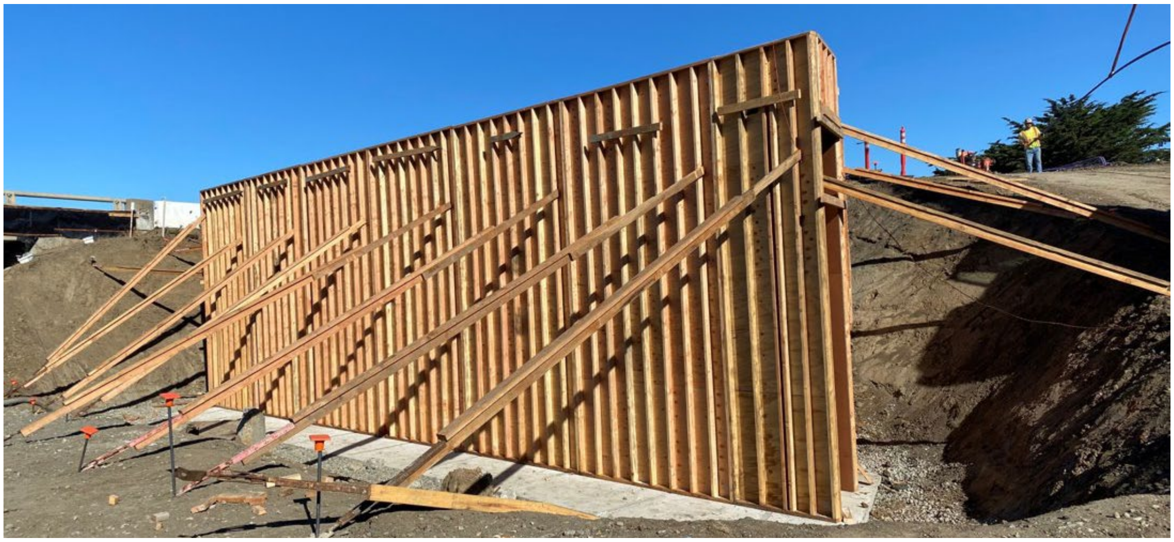

Figure 3-3. Concrete Forms Braced with Kickers

Gang forms are typically used for the construction of large-scale structures such as tall retaining walls and CIP concrete bridges. On concrete bridges, they may be installed on conventional falsework systems to form the bridge soffit. These prefabricated panels typically consist of an 8- by up to 40-foot-long panel comprised of plywood nailed to 2-by-8-inch joists, or similar; see Figure 3-4. When the soffit gang form panels are erected onto the falsework stringers, they are typically placed with a gap between each panel, which aids in the erection and removal of the panel system. This gap is typically bridged with a form filler panel (filler strip of plywood), as illustrated in Figure 3-5. Figure 3-6 depicts a typical completed soffit that was formed with gang forms.

Figure 3-4. Typical Gang Form

Figure 3-5. Form Filler Panel

Figure 3-6. Completed Soffit with Gang Forms

Chamfers are wooden triangular-shaped fillets used at form panel intersections to prevent mortar runs and bevel the corners of panel joints. Forms for exposed surfaces must be constructed with triangular fillets not less than ¾ by ¾ inches attached to produce smooth, straight chamfers at all exposed sharp edges of the concrete. They are also used as grade strips or pour strips to delineate the top of the pour within the forms. Chamfers are also commonly used to create the drip grooves for concrete box girder bridges. These drip grooves are detailed in Standard Plan B7-1, *Box Girder Details*. See Figure 3-7 for chamfers used in construction.

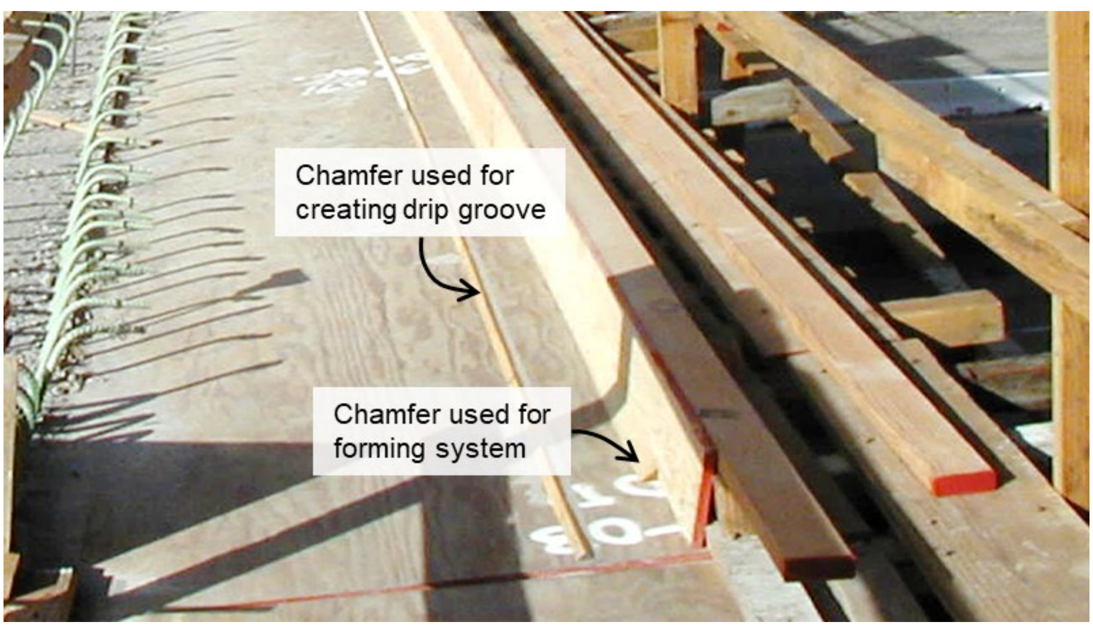

Figure 3-7. Chamfers Used for Bridge Construction

Expanding foam may be used to fill incidental gaps and ensure forms are effectively placed flush against concrete in areas around columns and abutments. Care must be taken when determining the product’s expansion capabilities. Excess foam that protrudes into the concrete section must be trimmed off.

3-3.01 Form Fasteners

Form fasteners are bolts, clamps, or other devices used as necessary to prevent the forms from spreading during concrete placement. The requirements for form fasteners are provided in *Contract Specifications*, Section 51-1.03C(2)(a), *Concrete Structures – General – Construction – Preparation – Forms – General* and Section 51-1.03F(2), *Concrete Structures – General – Construction – Finishing Concrete – Ordinary Surface Finish*. Form fasteners and anchors must be a type that can be removed in accordance with ordinary surface finish specifications, without chipping, spalling, heating, or otherwise damaging the concrete surface. Remove metal fasteners to a minimum of 1 inch below the concrete surface.

Note: Using twisted wire loops to hold forms in position is not permitted, except as specified by *Standard Special Provisions*, Section 51-4.03G, *Precast Concrete Members – Construction – Deck Panels*.

Concrete form ties, also known as snap ties, he-bolts, she-bolts, taper ties, tie rods, or form clamps are tensile units used to prevent the spreading of the forms during concrete placement. The most common ties used in bridge construction consist of an internal tension unit and an external holding device. Ties can have built-in spacers or spreaders to keep the forms a set distance apart. Some ties are designed so that they can be removed, or have portions of them removed, at a certain depth from the surface of the concrete. There are two basic types of internal tension units: continuous single-member and internal disconnecting member.

Continuous single-member ties consist of a single-piece tensile unit and a specially designed holding device that is used to hold the tensile unit tight against the exterior of the form. Some of these ties have an integral form-spreading feature that is built into the tie. The common concrete snap-tie used in bridge construction is snapped at a predetermined depth where the rod section has been weakened to facilitate “snapping.” Some single-member ties, such as she-bolts and taper ties, may be pulled and completely removed from the concrete.

The internal disconnecting member has an inner tensile unit with a threaded sleeve connection to a removable external member (bolt). The internal member remains in the concrete, while the outer is removed by unthreading from the coupling sleeve. This type of tie is available for light or medium loads but finds its greatest application under heavier construction loads.

Tie wedges are metal plates used in conjunction with concrete ties to distribute the load from the concrete tie to a larger area on the formwork element, usually the form walers. Wedge shaped in profile, the tie wedge slips over the head of a snap tie and is used to tighten the snap tie against the form by driving the wedge until there is no slack in the concrete tie. After the tie is sufficiently tensioned, the tie wedge is nailed to the form to ensure that it will not move and loosen during concrete placement. Figure 3-8 shows various examples of form fasteners.

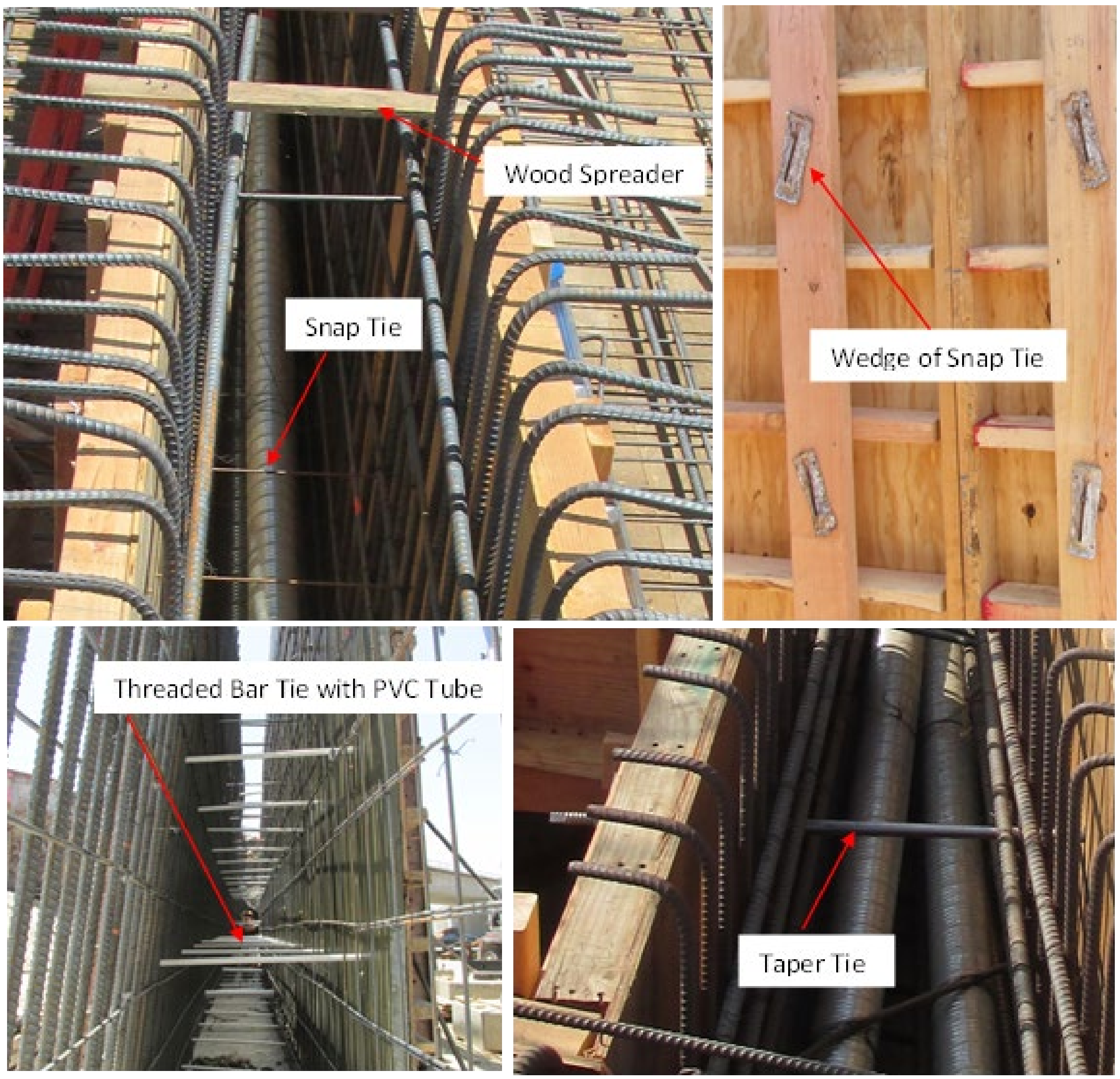

Figure 3-8. Examples of Form Fasteners

Spreaders are devices that maintain the correct spacing between the opposite faces of a formed element, such as those of walls or box girder bridge stems. Spreaders may be integral or fabricated with concrete ties. They may also be custom-made, usually from dimensional (typically 2-by-4-inch) lumber, cut in the field to the exact width of the formed element. Contractors sometimes employ a concrete tie with both an integral spacer and a custom-made wood spreader to ensure that the correct width is maintained, especially as the ties are tightened. Wood spreaders cannot be left embedded in the concrete and must therefore be removed during the pour. Contractors commonly tether these spreaders to adjacent stirrups to ensure they don’t fall into the concrete during placement.

Form anchors are devices that are cast into the concrete for later use in supporting forms or for lifting pre-cast members. There are two basic parts: the embedded anchoring device, whose design varies with the load to be carried and the strength of concrete in the structure; and the bolt or other external fastener, which is removed after use, leaving a set-back hole that must be patched.

3-3.02 Form Liners

Projects may require the use of form liners to create a specified concrete surface texture for CIP concrete structures. The term “form liner” refers to any sheet, plate, or layer of material attached directly to the inside face of forms to provide a desired surface texture or pattern to the finished concrete. While plywood, hardboard, and steel can be used as form liners, the term generally refers to material described in *Contract Specifications*, Section 51-1.03G(2), *Concrete Structures – General – Construction – Concrete Surface Textures – Form Liners.*

Elastomeric liners are made of rubber-like plastic formulations that are flexible enough to be peeled away from cast concrete surfaces. They require structurally adequate support and are usually attached to form sheathing. Elastomeric liners are durable material and can be frequently reused with reasonable care. Figure 3-9 illustrates retaining wall forms utilizing form liner.

Inspect form liners prior to every use to ensure the integrity of the surface. Verify that form liner panels are properly assembled and aligned. For fractured rib texture, verify that the raised surface between the ribs has random texture. This will safeguard against repetitive fractured surfaces or secondary shadow patterns, which are not allowed per *Contract Specifications*, Section 51-1.03G(1), *Concrete Structures – General – Construction – Concrete Surface Textures – General*.

Ensure that form liners do not reduce the specified thickness of the concrete element. For example, when verifying formwork for a retaining wall, avoid the common mistake of measuring to the form sheathing (plywood) instead of the innermost point of the liner texture. Refer to the project plans for details on wall thickness, and the relationship between the layout line (LOL) and the architectural treatment.

Form liners must be released from cured concrete such that the surfaces of concrete are not damaged. After they are released, form liners that are to be reused must be properly cleaned and maintained in accordance with the manufacturer's instructions.

Figure 3-9. Form Liner Panel

3-3.03 Steel Forms

In bridge construction, steel forms are commonly used for casting columns (Figure 3-10) and barrier rails (Figure 3-11). Most of these elements have standardized shapes and sizes. The durable nature of steel forms makes them economical for repeated use. Steel forms for barrier rails come in straight 10-foot sections and may not be suited to form barrier rails with tight radii. Steel forms are also commonly used in pre-casting yards where repeated use of a standard form is the norm. Inspect steel forms for dents, creases, or other damage upon delivery. Minor damage can be repaired with an acceptable filler material.

Figure 3-10. Steel Forms for Columns

Figure 3-11. Steel Forms for Barrier Rails

3-3.04 Fiber Form Tubes

Fiber form tubes are typically used in bridge construction to form the exposed portion of "pile-extension" columns in slab bridges. Fiber form tubes are complete units with no extra fastenings and require only a minimum of external bracing to keep them plumb. Where the columns are exposed, the inner surface is coated with polyethylene. Tubes can be saw cut to length. Cut sections can be adapted to form half-round and quarter-round surfaces. They are also used to form the voids in voided slab bridges, as illustrated in Figure 3-12. Sonotube® is a proprietary trademark for the most widely available cylindrical fiber form.

Figure 3-12. Fiber Forms Used for Forming Voided Slab Structure

3-3.05 Permanent Steel Deck Forms

Permanent Steel Deck Forms (PSDF), also referred to as stay-in-place forms (see Figure 3-13 and 3-14) may be used to form the underside of reinforced concrete bridge decks where specified for use in the contract documents, and as outlined in *Contract Specifications,* Section 51-1.03C(2)(c), *Concrete Structures – General – Construction – Preparation – Forms – Permanent Steel Deck Forms.* Unlike most forms, PSDF are left in place after the deck is cast and become permanent features of the bridge. The Contractor is obligated to submit PSDF shop drawings per *Contract Specifications*, Section 51-1.01C(2), *Concrete Structures – General – Submittals – Permanent Steel Deck Forms*. Review and authorize these shop drawings in accordance with *Contract Specifications*, Section 5-1.23, *Control of Work – Submittals.*

Figure 3-13. Permanent Steel Deck Forms (View Above Deck)

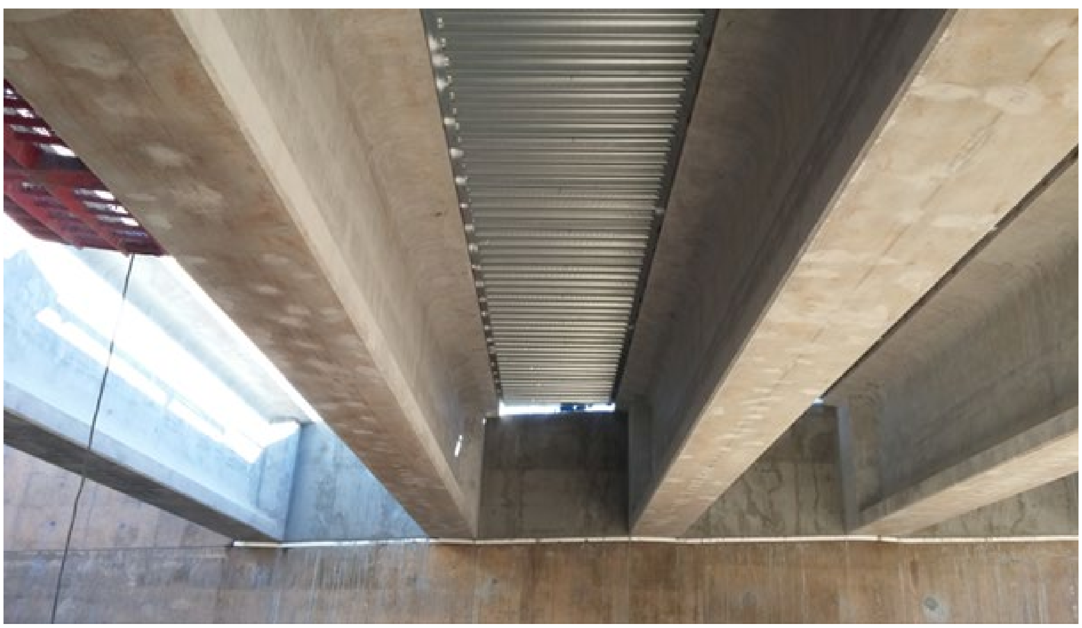

Figure 3-14. Permanent Steel Deck Forms (View Below Deck)

If PSDF are not specified in the contract but proposed for use by the Contractor, their use should be discussed with both Bridge Design (BD) and Structure Maintenance and Investigations (SM&I) to determine whether the proposal merits further discussion, and what design and/or maintenance considerations need to be addressed. Both the BD Project Engineer and SM&I must concur with the change order.

3-4 Form Workmanship

The actual size, shape, and alignment of abutments, columns, superstructure, and other concrete structural components and elements depend on the accurate construction of forms. The forms must be built to the correct dimensions, must be sufficiently rigid under the construction loads to maintain the desired shape of the concrete, must be stable and strong enough to maintain large members in alignment, and must withstand handling and reuse without losing their dimensional integrity.

The appearance of a finished concrete structure depends to a great extent on formwork quality, particularly the adequacy of the formwork to withstand the loads imposed by the concrete while it is in a plastic state without appreciable settlement or deflection. The behavior of formwork, as it is loaded, depends on the strength of the material supporting the form, the support system used, the quality of the form materials and workmanship, the forming method employed, and the rate and method of concrete placement. The formwork must remain in place until the concrete has hardened enough to maintain its cast shape.

The quality of the concrete surface finish is affected by the form panel material. For example, if a patterned or textured form liner is used, the liner must be properly supported so that it will not deflect and cause indentations in the concrete surface. The correct combination of quality form material and adequate releasing agent can contribute to eliminating air holes or other surface imperfections in the cast concrete.

Good workmanship in form construction should be as important to the Contractor as to the Department since the degree of care taken when building forms will determine the amount of subsequent work needed to obtain the required finished product. For example, grout leakage from forms that are not mortar tight will increase the surface finishing required (see Figure 3-15). Dirty form surfaces and form panels with worn or ragged edges will also increase surface finishing costs. Improperly braced forms will deflect, in which case remedial work may be necessary to obtain the required line, grade, and undulation limit specified in the contract documents.

Figure 3-15. Grout Leakage at Form Tie

The Contractor is not contractually forbidden to place new plywood next to old plywood; however, for exposed concrete surfaces or other locations where concrete surface appearance is important, doing so will likely produce an unacceptable, non-uniform concrete surface that will not meet finish requirements. Although not mandatory, contractors should consider “aging” new plywood if they plan to intermix them with older plywood. One method to accomplish this is to apply cement and water paste on the new material, then remove the paste after it dries. The dried cement paste absorbs the fresh wood sugar from the new plywood so that the finished concrete will have a color and texture similar to the color and texture of the seasoned plywood forms.

Additionally, the ability to produce a uniform appearance for exposed concrete surfaces will be affected by the placement of plywood used as form panels. Refer to *Contract Specifications,* Section 51-1.03C(2)(a), *Concrete Structures – General – Construction – Preparation – Forms – General,* for requirements for size uniformity, alignment, and symmetrical arrangement of form panels. Figure 3-16 shows form panels that have been properly sized and arranged.

Figure 3-16. Bridge Abutment Form Panels Properly Sized and Arranged

For exposed concrete surfaces, it is also essential to use the proper type of form tie or hanger that will not leave exposed metal at the concrete surface. If any moisture reaches the end of the tie, rust stains will appear on the surface of the concrete. A greater depth of break-back or threaded ends of internally disconnected tie units allows a better chance of bonding the patch that covers the tie, and less chance of the patch spalling or cracking. Although the patch remains in place, it may shrink and leave fine cracks through which moisture and rust gradually seep. Because it is non-corroding, a glass fiber-reinforced plastic tie, commonly referred to as a fiberglass tie, may be removed flush with the concrete surface, leaving no hole to patch.

As mentioned previously, forms must be mortar tight to prevent grout leakage. This requirement is particularly important for soffit forms located above traffic openings or forms near environmentally sensitive areas. The use of thin metal strips, plastic sheeting (Visqueen), spray foam, caulking, or other materials can reduce the risk of leakage. Although not contractually required, it is a highly recommended best practice to place plastic strips or similar material underneath the unsupported soffit plywood seams at these locations. See Figure 3-17 for an illustration of this proactive practice.

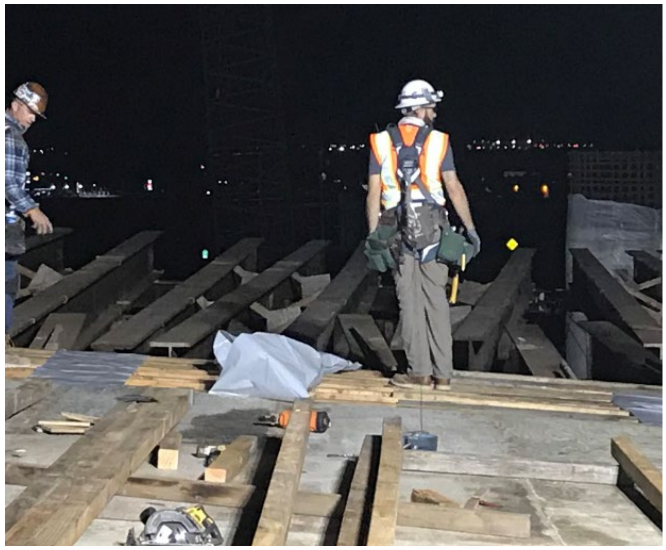

Figure 3-17. Plastic Placed Under Soffit Plywood Seams Over Traffic Opening

Inspect the forms sufficiently in advance of placing rebar and concrete to provide time for repairs without impacting the schedule. In addition to items discussed in this section, other common issues to look for include:

1. Loose form filler strips (e.g., form filler strips that are not firmly nailed to the joist).
2. Damaged and warped panels from overuse or exposure to weather.
3. Non-uniform filler strip widths.
4. Non-uniform form line patterns, particularly on skewed bridges.

Note in daily reports when the Contractor is notified of necessary corrective actions and when they are completed and accepted. Form panels that have minor damage or are damaged (damaged corners, holes, delamination, and scars) after installation and cannot reasonably be replaced may be repaired when using acceptable methods and materials, such as custom-cut wooden patches (referred to as “Dutchman”), wood fillers, resin products (Bondo), and wood or cork plugs. Building paper must not be used to patch cracks or holes in lost deck forms. Tin sheet metal or wood is acceptable, provided it does not infringe on the required deck thickness. Inspect forms again immediately before concrete placement to verify they remain in acceptable condition.

3-5 Formwork Design

Contract Specifications, Section 51-1.03C(2), *Concrete Structures – General – Construction – Preparation – Forms*, provides requirements for formwork. Although it is not required, *Contract Specifications*, Section 51-1.01C(1), *Concrete Structures – General* **–** *Submittals – General,* provides SC staff the right to request a concrete form design and materials data to be submitted for each forming system. It may be prudent to request that the Contractor provide details of the forming system for the Engineer’s review and meet to discuss any concerns about the adequacy of the formwork.

3-6 Formwork Design Review

3-6.01 Lateral Loading

Determining the appropriate lateral loading to be used in form design is a subjective exercise. This lack of precision is because the basic component of lateral loading and the fluid pressure of fresh concrete is governed by the unit weight of concrete and affected by several variables such as the type of cement, concrete temperature, concrete penetration (slump), consolidation method, and rate of concrete placement. ACI 347 *Guide to Formwork for Concrete*, published by American Concrete Institute (ACI), provides guidance for determining loads based on dimensions, placement rates, and other factors.

3-6.02 Unit Weight of Concrete

The basic component of the lateral loading on the forms is the unit weight of concrete. Freshly placed and vibrated concrete behaves temporarily like a fluid imparting lateral pressure on the vertical surfaces of the forms. If concrete is considered an idealized fluid, then the pressure on the form during concrete placement follows the standard fluid pressure formula:

$$\mathbf{P} = \mathbf{wh} \qquad 3\text{-}6\text{-}1$$

Where "**w"** is the unit weight of concrete in pounds per cubic foot (pcf) and "**h**" the height in feet of concrete over a given point. 150 pcf is a commonly assumed unit weight of concrete for the sake of convenience.

However, fresh concrete is a mixture of cementitious materials, aggregates, and water whose behavior only approximates that of a true fluid for a limited time. The effective lateral pressure used in form design is a modified hydrostatic pressure, where its basic component, the unit weight of concrete, is adjusted by concrete placement factors such as temperature of the concrete mix, rate of placement, the admixtures and cement blends used, and effects of vibration or other consolidation methods.

3-6.03 Rate of Placement

One of the most significant factors affecting the lateral pressure on concrete forms is the average rate of concrete placement. As soon as concrete is placed, it starts to become less fluid and lose its capacity to translate the weight of subsequent concrete layers as additional lateral pressure on the forms. This reduces the hydrostatic head to only those layers where concrete is still fluid, thereby decreasing the effective fluid pressure on the form. With slower rates of placement, concrete at the bottom of the form begins to harden, and the lateral pressure is reduced to less than the idealized fluid pressure by the time concrete is placed in the upper parts of the form.

3-6.04 Temperature

The temperature of the concrete during its placement also influences effective pressure on concrete forms because it affects the setting time of concrete. At low temperatures, the concrete generally stays fluid for a longer period, allowing for more concrete to be placed before the lower portion becomes firm enough to be self-supporting. The greater hydrostatic pressure head due to the lower concrete temperature results in higher lateral pressures. This must be considered when designing forms for concrete to be placed during cold weather.

3-6.05 Vibration

The method of consolidating concrete inside the forms is also a factor that affects the magnitude of the effective fluid pressure. Consolidating concrete using internal vibrators results in an increase in temporary lateral pressures, because it causes concrete to behave as a fluid for the full depth of vibration, generating approximately 10-20 percent greater pressure in the localized area of vibration. If external vibrators are used, the loads they exert on the forms must also be taken into consideration in form design. Essentially, the forms “hammer” against the concrete.

3-6.06 Admixtures

Chemical admixtures and supplementary cementitious materials have significant effects on lateral pressure. They may slow down or accelerate the rate at which the concrete hardens. The chemistry coefficient, $\mathbf{C_c}$, introduced in ACI 347, provides a way to quantify the effect of a number of these variables, on lateral pressure.

3-7 Formwork Removal

The contract requirements for form removal, also known as stripping, are found in *Contract Specifications*, Section 51-1.03C(2)(b), *Concrete Structures – General – Construction – Preparation – Forms – Removing Forms*. Be aware of the requirements of *Contract Specifications*, Section 90-1.03B, *Concrete – General – Construction – Curing Concrete*. Unless the concrete is cured using the “Forms-in-Place Method”, per *Contract Specifications,* Section 90-1.03B(5), *Concrete – General – Construction – Curing Concrete – Forms-In-Place Method,* the Contractor must be prepared to immediately apply one of the other approved curing methods provided in *Contract Specifications,* Section, 51-1.03H, *Concrete Structures – General – Construction – Curing Concrete Structures,* before starting form removal.

3-7.01 Form Release

The specifications require that forms to be removed must be thoroughly coated with oil before use. Form oil is applied to form sheathing to prevent concrete from bonding to the form, permit its ready release, and keep the formwork clean. Form liners require application-specific form release agents. Follow the manufacturer's recommendation for form release agents or discuss with the Materials Engineering and Testing Services (METS) Representative. Ensure that the form release agent does not discolor the concrete. If in doubt about the efficacy of or potential discoloration caused by the product, have the Contractor cast a test sample.

Without form release agents, the forms will adhere to the surface of the concrete when the forms are stripped, creating rough, irregular, spalled surfaces. The resulting effect necessitates costly and lengthy refinishing of the exposed concrete surface. The form release agent must not contact the bar reinforcement. Otherwise, it may prevent or reduce the bonding between the concrete and steel necessary to develop the composite function of reinforced concrete. Accordingly, it is standard practice to apply form release agents to the formwork prior to the placement of bar reinforcement.

While the specifications only require a commercial quality form release agent that will permit the ready release of the forms, there are products that are specifically formulated as form release agents. In general, there are two broad categories of form release agents: barrier type and chemically active. Barrier types are water-insoluble materials that include neat oils, paraffin wax, and silicone oil. The Environmental Protection Agency prohibits the use of uncut or straight diesel oil as a release agent. Chemically active agents have fatty acids that chemically react with materials in portland cement paste and produce soap, a film that prevents the concrete from bonding to the form surface.

There has been increasing concern about the use of form release agents in applications over bodies of water; check with the Storm Water Pollution Prevention Plan or regulations of the local Regional Water Quality Control Boards on product limitations. Local and federal regulations on volatile organic compounds (VOCs) may need to be considered when selecting the appropriate release agent.