The Contractor's Guide to Quality Concrete Construction

Third Edition

AMERICAN SOCIETY OF CONCRETE CONTRACTORS

AMERICAN CONCRETE INSTITUTE

American Concrete Institute®
Advancing concrete knowledge

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Photo Credit: Bottom photo on cover depicting formwork courtesy of Meva Forms.

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Foreword
Safety

While there are many things important to concrete construction, such as quality work and making a profit, safety must always be the number one priority. For that reason, safety is in the front of this book to emphasize its importance as critical to a successful project.

Construction can be a hazardous business. With proper training procedures, hazard inspections, and rules enforcement, however, the hazards can be greatly reduced or eliminated.

A well-conceived safety program is mandatory to keep everyone at the jobsite aware of possible hazards. People attracted to construction work tend to feel that they can "take care of themselves." While that may generally be true, concrete construction involves teamwork. You must consider the safety of others as you work. Without safety awareness, the self-confidence of a construction worker can create the attitude that safety regulations and protective equipment are an annoyance rather than a necessity. The "rookie" is the most feared person in construction. "Rookies" are exposed to more unknowns than those workers who are familiar with the project. Careful and complete safety training for "rookies" will produce safer and more efficient crews.

Failure to follow safety regulations and to use personal protective equipment can lead to injuries. Lost-time injuries tend to be severe, costly to both the company and the injured employee, and may even lead to a long-time or permanent reduction in a person's physical abilities.

In addition to the concern for the injured person, the company loses that person's skills and faces a potential drop in the quality of the work during the time that worker is off the job. Accidents disrupt the flow of work, causing further impacts to the project.

Most Accidents Are Not Accidents

Most accidents are preventable. Accidents are often due to carelessness in not thinking through what we are doing. You MUST plan for safety.

How many times have we used an overloaded or damaged forklift or other faulty equipment as the result of our desire to quickly complete a task? How many times have we not stopped to sand a slippery working surface, or lifted with our backs when we're tired?

Time spent for safety training is a basic cost of the construction business that pays off in increased production, lower insurance rates, and less lost time of skilled craftsmen. The full cost of accidents will far exceed the costs of a good safety program. Safety can be a profit center in both human and financial terms.

The Need for a Company Safety Program

This chapter is not a safety manual for concrete construction. The American Society of Concrete Contractors has published the *ASCC Safety Manual* that everyone working in concrete construction should read and periodically reread. You should also be familiar with the regulations of appropriate governmental agencies, especially those of the Occupational Safety and Health Administration (OSHA).

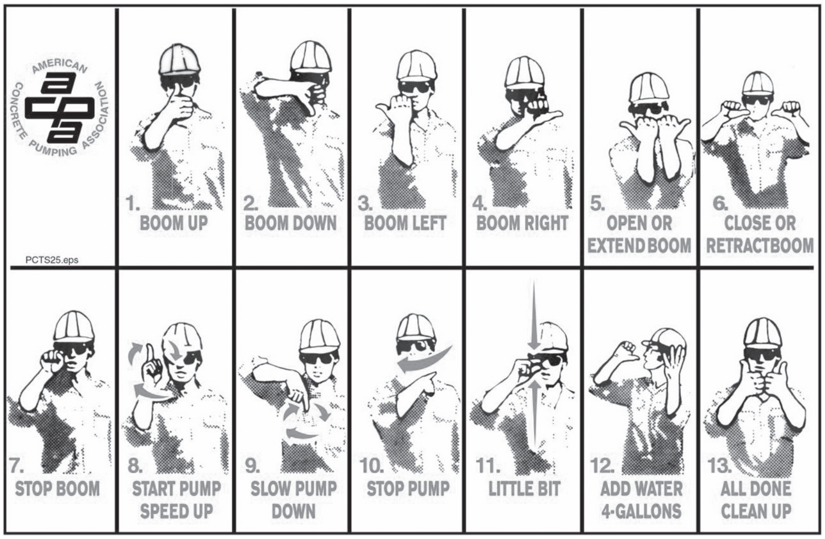
Every concrete project is unique. Casting a slab on ground is quite different from casting the 40th floor of a high-rise office building. Each has dangers that can be avoided, if we are aware of those dangers. That is why, in addition to the *ASCC Safety Manual*, every contracting firm must develop a written safety policy that sets out clear lines of authority for training new personnel and retraining long-term personnel in safety regulations and procedures related to their construction specialty, and in hazard recovery.

Every company is responsible for providing safe working conditions, and every person is responsible for following the safety rules of their company and making safety a part of their job. Helping new employees adjust to the specific dangers of the jobsite through training and mentoring are components of a successful safety program.

Concrete Construction

The following list of things to watch out for on a concrete construction jobsite is not intended to be comprehensive. This listing does, however, serve to alert you to *some* of the more common safety concerns of concrete construction:

- Fresh concrete can cause eye injuries and skin burns. When working with fresh concrete, wear protective clothing (long-sleeved shirt, rubber boots, and rubber gloves) and eye protection to avoid getting fresh concrete on your skin or in your eyes. If you do get fresh concrete on your skin, wash it off with clean water. Have eye wash solution on the job. Should concrete splash in your eye, flush the eye with clean water immediately, and obtain prompt medical attention. Think ahead. Have a supply of clean water and eye wash solution available whenever concrete placement is scheduled. And remember that the tool clean-off bucket is not clean water.
- Among concrete workers, the most common skin disorders are dry skin, irritant contact dermatitis, allergic contact dermatitis, and cement burns. The best way to keep skin healthy is to wear gloves and practice good hygiene. Wash your hands 2 to 4 times a day and whenever you remove your gloves, using pH-neutral or slightly acidic soap. Placement crew members should wear long-sleeved shirts and long pants, protective goggles or face shields, hardhats, chemical-resistant gloves, and over-boots. Finishers should wear long pants, work boots, knee pads (and use knee boards), and gloves. Immediately remove clothing that has become saturated with wet concrete.
- Keep your fingers away from the metal joints of a ready-mix truck chute. These are heavy! Should a finger be caught in the gap of the joint as the heavy chute is dropped from its folded, stored position, it can slice through a finger like scissors through cloth.
- The simple use of personal protection equipment (PPEs) can save workers from the short-term and long-term effects of construction site conditions (hard hats, gloves, boots, eye protection, fall protection, respirators, etc.). Have PPEs available and wear them!
- Safety glasses or goggles must be worn whenever there is the possibility of getting anything in your eyes.
- Ear plugs must be used when the noise level gets to the point where you have to raise your voice to speak to the person working next to you. It doesn't take much exposure to noise to permanently damage your hearing.
- Dust masks or respirators must be worn whenever there's a chance of inhaling dirt, dust, chips, or mist; when you are cutting, grinding, or chipping hardened concrete; or when you are mixing epoxy or grout. Be sure to ask for training in the selection and use of a proper respirator. Another solution to this problem is to use wet methods, or "dustless" vacuum tools.
- Ladders and stairways are a major source of injuries and fatalities among construction workers. Employers should ensure that employees are trained by a competent person in the nature of fall hazards; the correct procedure for erecting, maintaining, and disassembling fall protection systems; proper construction, use, placement, and care in handling stairways and ladders; and the maximum intended load-carrying capacity of ladders.
- Do you know how to properly set an extension ladder? The distance along the ground from the bottom of the ladder to a point beneath where the ladder is supported near its top should be about a quarter of the length of the ladder. If the slope is flatter than that, the ladder can easily become overloaded. If it's steeper, the ladder can fall. The ladder must be secured at both the top and bottom against displacement.
- Scaffolding should be solidly constructed, even if it is to be used only for a short time. Be sure uprights are uniformly spaced, plumb, and set on a good solid foundation. Use horizontal or diagonal bracing for stability. Planking should overlap the support by a minimum of 12 in. Scaffolding should be tied to walls, buildings, or other structures. A competent person should inspect the scaffolding daily.
- The most hazardous moment when working at heights is when you are moving from place to place. That's why you need to always be tied off to something substantial—something that can support a dead weight of 5000 lb. Any time you go over a guardrail to perform work, you must be tied off. Fall protection should also be worn when working at ground level around open excavations 6 ft or more in depth. Be sure to place guardrails around openings in decks.
- When welding or burning metal embedded in concrete, wear eye and face protection to protect yourself from flying pieces of concrete. Concrete can spall off, almost explosively, when heated by a torch.
- Treat compressed gas cylinders with respect. Secure the cylinders upright by tying them off or using other means to prevent them from moving freely.



- Use ground-fault circuit interruption devices at all times when using vibrators and other electrical tools. Wet concrete and water are excellent conductors. These devices will prevent electrocution.
- Electrical cords and tools must be inspected daily and repaired or replaced if damaged. Protect electrical cords by placing them in protected areas or by covering them with protective material.
- Keep the jobsite clean—even if it's not your job. It's far better to pick it up than to fall over it. A clean jobsite sets the tone for efficiency and quality workmanship.
- "Of all heavy equipment, mobile cranes are the least forgiving of misuse, abuse, and neglect," according to *Construction Equipment* magazine (June 1985). Stay out from under suspended hooks and loads. Think of the swing area as no-man's land and stay away.
- Make sure that wire rope, slings, shackles, and other lifting devices are sized correctly and inspected thoroughly before using. If something breaks under a lifting load, a lot of energy can be released. A flying cable can remove an arm or leg in an instant.
- Never walk underneath a load being lifted.
- To avoid electrocution, never touch a piece of equipment that is working near power lines.
- Do not allow pump trucks, cranes, forklifts and other equipment with high profiles to work within 15 ft of 50,000 kv or lower electrical lines. Higher voltage lines require even greater distances.
- Make sure that the person guiding a pump operator knows and uses the standard hand signals developed by the American Concrete Pumping Association.
- Watch where you are walking to avoid falls. If you see a board with nails sticking up, stop and pull them out or bend them over to prevent someone from stepping on a nail.
- Bend with your knees and lift with your legs, not your back.
- Lift only what you can comfortably handle. Get help with heavier or bulky items.
- Check equipment and tools before each shift to ensure they are in proper working condition.
- Keep the material safety data sheets (MSDS) for the chemicals on your project up-to-date and easily accessible. Have employees review this information before using new products on site.

Please remember, accidents don't just happen—they are caused. They are more often than not the results of poor planning, improper training, or not thinking through each of your work activities. For example, if you throw a chain up and over a beam, think about where the hook on the free end is going to swing and move out of the way before it does!

Experience Modification Rating and Incident Rate

The cost of workers' compensation insurance is directly affected by your company's accident history. When an employee is injured, the costs are added to the company's experience modification rating (EMR). Accidents can increase a company's EMR to where it significantly increases their workers' compensation insurance rates. A large component of any company's insurance rates are the cost of past claims. This cost can be controlled. Effectively implemented, a safety program can help to reduce insurance rates and make a company more competitive and more profitable.

Another measure of safety is the incident rate, a nationally recognized number that equalizes the accident rate for firms of all sizes. The incident rate represents the number of lost workdays for 100 employees working

40 hours per week for 50 weeks per year. The incident rate is calculated as the number of lost workday cases from a company's OSHA Form 300, Log of Work-Related Injuries and Illnesses, times 200,000, divided by the number of total work hours in a calendar year. Expressed as an equation

$$IR = (N \times 200{,}000) \div WH$$

where:

IR = incident rate

N = number of lost workday cases away from work for both injuries and illnesses. This number is the sum of the check marks in column H on OSHA Form 300.

WH = the total number of work hours for the company in a calendar year, which includes everyone on the payroll, hourly and non-hourly, including overtime.

For example, the incident rate for a company that has 10 lost workday cases and 40,000 work hours is

$$IR = (10 \times 200{,}000) \div 40{,}000 = 50$$

Recommended Reading

ACI Committee E 703, "Formwork Safety," Topic 24, *Toolbox Meeting Flyers 2*, American Concrete Institute, Farmington Hills, Mich., 1998.

ASCC Safety Bulletins, The American Society of Concrete Contractors, St. Louis, Mo.

ASCC Safety Committee, *ASCC Safety Manual*, Third Edition, American Society of Concrete Contractors, St. Louis, Mo, 1999.

Occupational Health and Safety Administration, www.osha.gov.

PCI Erectors Committee, *Erection Safety for Precast and Prestressed Concrete,* Precast/Prestressed Concrete Institute, Chicago, Ill., 1998.

Pump Safety, American Concrete Pumping Association.

"Safety Basics Posters," 18 x 24 in. posters on safe construction practices, Hanley Wood, Addison, Ill.

"Skin Safety with Cement and Concrete," Training Videos, Portland Cement Association, Skokie, Ill., 1998.

Contents

Chapter 5: Formwork

Fresh concrete is a plastic material that takes the shape of the container or form into which it is placed. A *form* is defined as a temporary structure or mold for the support of concrete while it is setting and gaining sufficient strength to be self-supporting (ACI 116R-00). *Formwork* has a broader definition: it is the total system of support for freshly placed concrete including the mold or sheathing which contacts the concrete, as well as all supporting members, hardware, and necessary bracing (ACI 116R-90).

Forms are essential to concrete construction. They mold concrete to the desired size and shape and control its position, alignment, and surface contour. And, as defined above, formwork is more than a mold. It is a temporary structure that supports its own weight, the weight of the freshly placed concrete, construction loads such as materials, equipment, and workers, and other possible live loads during construction such as heavy snow on a slab.

Formwork costs range from 35 to 60 percent of the cost of a concrete structure, so it is important that the contractor aim for maximum economy without sacrificing safety or quality. The proper selection of materials and equipment, careful planning of fabrication and erection procedures, and efficient reuse of forms can expedite the job, assure the best use of labor, and save money. This is accomplished with advanced planning and scheduling. (Refer to Chapter 9 for a preconstruction checklist.)

The formwork phase of a project can be the most costly and dangerous of the functions on a jobsite. While economy and quality are important, safety must be of prime concern. The formwork must be capable of supporting loads without collapse or danger to workers or the public (or to the new concrete structure). Concrete placed in or on formwork imposes loads on either the ground or existing structure. These loads should be checked (particularly in large structures and multistory buildings) by the project structural engineer to ensure that the magnitude, location, and timing of the imposed loads do not exceed (with an appropriate safety factor) the structural capacities of the foundation and structure.

The contractor takes on considerable responsibility in the design and erection of formwork. The importance of good communication between the builder and the designer cannot be overemphasized so that the construction is safe and the end result is what the engineer designed and specified and what the owner is paying for.

Safety Precautions

Attention to safety is critical in formwork construction. The formwork must support the concrete and construction live loads during its plastic state and until the concrete becomes structurally self-sufficient.

Safety begins in the estimating, planning, and management of a project. The forms must be correctly designed to handle expected loads, and this requires involvement of a design professional. Formwork designers must follow local code requirements for formwork as well as OSHA regulations. (Requirements for concrete, concrete forms, and shoring are found in Subpart Q of the Construction Safety and Health Regulations.) To ensure safe performance of the forms, the contractor's form designer should follow the design criteria contained in ACI 347R, "Guide to Formwork for Concrete."

Formwork failures can be attributed to lack of attention to detail, human error, substandard materials and equipment, omission, and basic inadequacy in design (underdesign). Take special care with self-consolidating concrete to avoid blowouts.

The most effective means of achieving safety in the use of forms is to have competent supervision and knowledgeable workers during formwork erection and concrete placement. Formwork must be constructed exactly as designed, following safe erection and stripping procedures, so that no members are temporarily overloaded. Construction procedures must be planned in advance to ensure the safety of personnel. The contractor should have a program of field safety inspection for formwork as the job progresses. Form watchers are needed to ensure early recognition of possible form displacement or failure during concrete placement.

The project manager or superintendent should develop a safety checklist. The ACI "Guide to Formwork for Concrete" (ACI 347R) lists some of the safety provisions that should be considered. A checklist for formwork can be found in the ACI Concrete Craftsman publication "Supported Beams and Slabs" (ACI CCS-3). The checklist refers to overall safety, wall and supported formwork, and shoring and reshoring.

The project checklist should be given to each foreman, and periodic meetings (weekly or even daily) should be held with the workers. Everyone on the project then becomes a safety inspector, and there will be fewer accidents and failures. A safe worksite also helps ensure high-quality concrete construction.

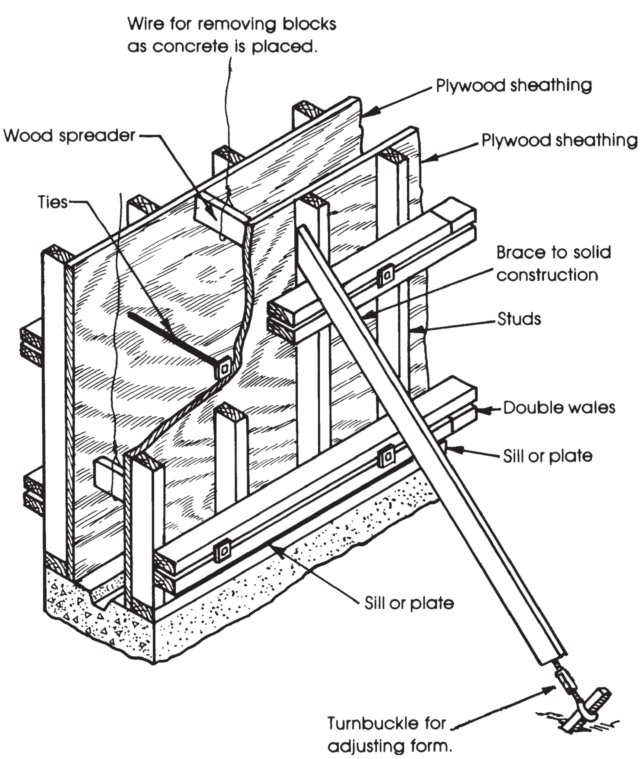


Fig. 5.1 — A typical job-built wall form. Wood spreaders are shown, but frequently the spreader device is part of the prefabricated metal tie.

Formwork Affects Concrete Quality

Size, shape, and alignment of slabs, beams, columns, and other concrete structural elements depend on accurate construction of the formwork. Forms must be built to the correct dimensions. Formwork must be rigid enough under construction loads to maintain the designed shape and alignment of the concrete element. If the forms deflect excessively, bulges in the concrete surface may require expensive chipping and grinding. If the forms move out of place, the misalignment can destroy the integrity of the structure or affect installation of the structural frame, the building's façade, or building equipment. The formwork must stay in place until the concrete is strong enough to carry its own weight and any external loads.

The quality of the surface finish of the concrete is directly affected by the forms and form material. Poor workmanship and a lack of attention to detail while installing formwork will lead to form concrete leakage and rough finishes. If the forms do not produce the specified finish, considerable corrective work such as grinding, patching, rubbing, or coating may be required.

If the job has unusual requirements or special architectural finishes for walls and columns or entails new techniques, it is a good idea to have the crews who will be doing the work construct sample walls or units. Mock-up panels and walls can be built to perfect concrete mixes, fine-tune construction techniques, demonstrate early-age strength, or provide an example of the surface finishes that should be expected. These panels can also help clarify the type of finish desired by the architect. Another place to try sample finishes, sandblasting, or coatings is on a wall that will later be backfilled or on an interior wall that will later be covered.

Types of Forms

Forms and forming systems usually fall into one of four categories:

- Job-built forms for one-time use. Form components are assembled piece by piece on the jobsite.
- Prefabricated job-built forms that can be reused, usually referred to as gang or ganged forms.
- Manufactured forms, generally purchased or leased, sometimes as a total system.
- Special form systems for specific situations or structures.

Job-Built Forms

Wood job-built forms are built in-place by assembling individual components piece by piece for some light construction projects, or for one-time use on any project. A typical wood job-built form, with components identified, is shown in Fig. 5.1.

Built-in-place forms are erected over a footing or concrete slab that acts as a platform for the wall form. The most common procedure is to fasten a base plate, or double base plate, to the footing or slab for the outside wall with powder-actuated fasteners or concrete nails. Wood studs are nailed to the base plate and can be tied together with a temporary ribbon board. The sheathing is nailed to the studs, and the wales are placed. These pieces are often assembled in advance as a complete panel and then hoisted into place. The inside form walls are constructed in a similar manner. Spreaders (wood or metal) are placed between inside and outside form panels. Wall ties are inserted through predrilled holes in the sheathing. The wall forms are aligned and braced.

Prefabricated Forms

While job-built forms for one-time use are used on many projects, labor costs and the potential for precision and economy with mass production have brought changes. Prefabricated, reusable form panels and shoring units have become standard items of construction.

Ready-made or contractor-built prefabricated panels are commonly used for wall forming, and also for deck forming where multiple floors are being erected.

For wall forms, the studs and sheathing are preassembled in units small enough to be handled conveniently. The panels are set in position and tied together with wales, braces, and ties. Panels are erected basically the same way as built-in-place forms.

Gang or ganged forms are built by assembling a number of smaller prefabricated panel forms into one large form (Fig. 5.2). Gang forms can be used on all types of work, their size being limited only by job conditions and the means for moving them. These large sections are erected, stripped, and moved to the next location by cranes. This method provides good reuse of equipment, larger concrete placements, and decreased erection and stripping time because the sections stay intact. No dismantling and reassembly of each individual panel is necessary for each concrete placement.

Gang forms are usually tied with taper ties and inner rods or she-bolts (Fig 5.14 and 5.15). The she-bolts are often used in thick walls and left in place. Taper ties must be removed completely and the holes patched.

Flying table forms are large prefabricated forms for multistory building slabs. They contain their own support system and leveling jacks, and are easily dropped away from the floor slab when the concrete reaches the specified strength. The form is then moved to the edge of the building, picked up by a crane, and moved to the next floor for setting and leveling. This is a very efficient forming system when the building geometry permits.

One-way and two-way joist pan forms can also be attached to the deck surfaces and "flown" into position with such a system.

Manufactured Forms

The basic concrete form that is built in-place on the job has been refined over the years. Now there are a number of specialty, manufactured forms that reduce the time and labor formerly required at the jobsite. These systems and panels are durable enough for many reuses. They are generally purchased or leased. Each proprietary panel system has its own special ties, connectors, and other accessories.

Pan forms made of metal, fiberglass, or plastic are used for floor slabs in multistory buildings (Fig. 5.3). Waffle slab floors have waffle-like indentations on the bottom surface formed by rectangular pans in the same manner as in the pan joist floor system (Fig. 5.4). These forms are reusable and can be either rented or purchased. They come in a wide range of sizes and depths.

Internal forms are round or rectangular laminated fiber and cardboard forms placed in deep (or thick) floors or beams and left in place to lighten the dead weight of the member (Fig. 5.5). These produce a floor slab similar to the pan joist floor except both top and bottom surfaces are flat. The duct-like voids create a space between the joists inside of the element. The ends of the tubes and boxes are closed off so that concrete will not flow into them. They are tied down with wire to prevent floating or lateral movement during concreting.

Expanded polystyrene can also be used to create internal voids. This material is rigid, lightweight, easily cut on the jobsite, and strong enough to withstand the usual pressure from freshly placed concrete. It must be tied in place to keep it from floating as concrete is placed.

Tunnel forms made of steel or aluminum combine the walls on either side of a room and the slab overhead soffit

Fig. 5.2 — Gang forms being flown into position. (Photo courtesy of MEVA Forms.)

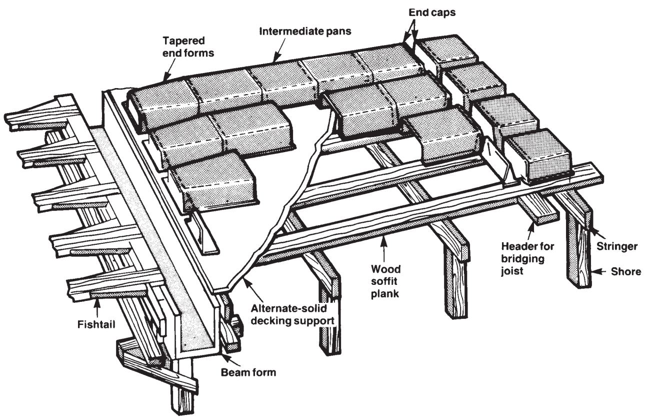


Fig. 5.3 — Nail-down pans for one-way joist construction.

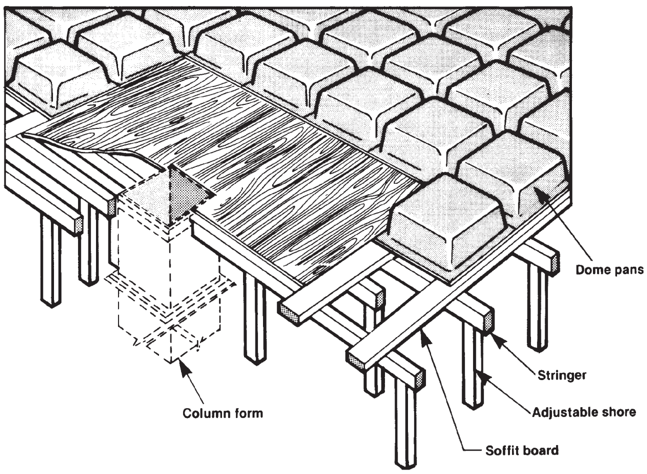


Fig. 5.4 — Dome pans for waffle slabs. Pans are omitted where solid construction is required around columns.

Fig. 5.5 — Voids are formed in the slab by laminated fiber tubes. The tubes are tied down with wire to prevent movement during concreting. (Photo courtesy of Sonoco Products Co.)

form into a single unit. Typically, the wall forms hinge to allow the slab soffit form to be stripped, and the entire assembly is hoisted to the next bay to be formed.

Panelized forms (or modular forms) prefabricated of plywood, aluminum, or steel are easily fastened together at the jobsite to rapidly form large areas of concrete walls. They offer three distinct advantages:

- Components can be assembled for almost any size or shape.
- There is less need for on-site skilled labor.
- The same forms can be used and reused as part of a large section and another time as individual units.

On-site skilled labor is reduced since almost all cutting, trimming, and fitting are eliminated. The use of a panelized system requires considerable lead time, however. The gains in on-site productivity are only accomplished with advanced planning, scheduling, detailed layouts, and constant site supervision.

Panelized prefabricated forms are generally manufactured in modular sizes. The 2- and 4-ft widths are the most common, with heights ranging from 2 to 12 ft. Many accessory panels are available, including small filler and corner units of varying size. Hardware and ties supplied with form panels vary with different manufacturers. Specialized patented hardware is a major component of all the panel systems.

Panel forming systems can be purchased or rented. Three basic types are:

- Unframed plywood panels, backed by steel braces with special locking and tying hardware.
- All-metal panels of plates supported by matching frames. These include aluminum panels that can create brick textures in a concrete wall (Fig. 5.6).
- Plywood panels set in a metal frame with metal bracing on the back.

Clamp-style gang form systems have been introduced to the market in the past few years and have proven beneficial in reducing the labor involved in the assembly and disassembly of the individual gangs, as well as in the handling involved throughout the normal form use on a given project. As formwork costs bear heavily on the overall concrete project, these forms offer an opportunity to reduce labor, speed cycles, and decrease the quantity of equipment on a project.

Compared to a 4 x 8 ft gang form system, which requires numerous steel wales and alignment channels and is assembled with a substantial quantity of hardware, clamp-style gang forms only require two or three clamps at each form joint that are installed with a couple of hammer blows. Wales and strongbacks are not needed, with the exception of aligning the horizontal joints when stacking. Even then, these systems usually provide a small steel wale that easily mounts to the back of the forms and properly aligns them. Since these forms eliminate hardware and heavy steel wales, their lesser weight can help lower the crane capacity required or allow the same crane to lift larger form sections.

Another attraction of these systems is simplicity. In an age where skilled labor is difficult to find, these systems can reduce the learning curve of workers not familiar with formwork. Their real advantage, however, is clearly visible on projects where certain buttresses and varying wall heights necessitate that quick alterations be made to the gang forms and the forming of the details (because of its simplicity and speed).

As with any other forming system, there are variations from one manufacturer to the other in available sizes, components, working-load capacity, and tying methods. These forms are usually available in metric sizes, but some manufacturers have also made them available in foot-inch units. These systems are usually available for both, rental or sale. Some suppliers will also include in their prices valuable services such as field consulting and form erection drawings so it's suggested that a contractor takes the time to explore and identify the right system and the right supplier for a specific need.

Column forms: Square or rectangular columns can be built using the same system of form panels as used for walls. Forms for round columns are available in laminated fiber, metal, and glass fiber-reinforced plastic as complete units.

Laminated fiber tubes (Fig. 5.7) are one-time use forms and require only minimum external bracing to keep them plumb. The tubes come in standard lengths and a range of diameters. The laminated forms can be cut with a saw and are easily stripped if removed shortly after casting, but will become more difficult to remove over time. Columns over 15 ft long often require stiffening on four sides to reduce the tendency of the fiber form to bend.

Ready-made steel column forms (Fig. 5.8) are assembled in sections, with necessary hardware being provided with the form. A capital (flared section at the top of a column) is a standard part of the form.

Fig. 5.6 — Cast aluminum forms with a patterned face produce a brick texture in the concrete wall.

Fig. 5.7 — Fiber tube column forms require bracing to keep them plumb and a template at the base for accurate positioning.

Removable forms, as they have come to be called, are aluminum form systems used primarily for

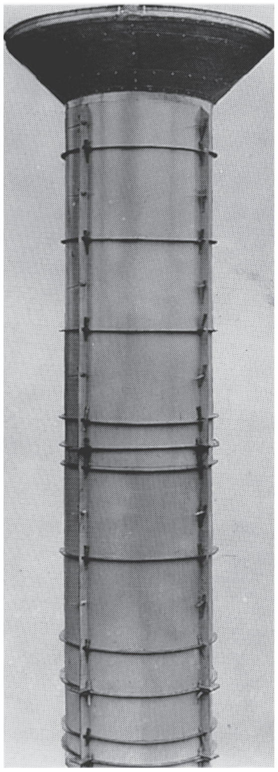


Fig. 5.8 — One of the several patented steel column forms (left) and a finished column after stripping (right).

Fig 5.9 — Stay-in-place corrugated metal forms are supported on precast concrete girders. Nails cast in the girders are bent over to hold the form in place.

residential construction. These form systems usually combine wall forms with an insulating polystyrene foam insert either on the inside or outside face or positioned in the middle of the wall. These proprietary systems sometimes incorporate floors and are pumped full to create an entire structure with a single pour.

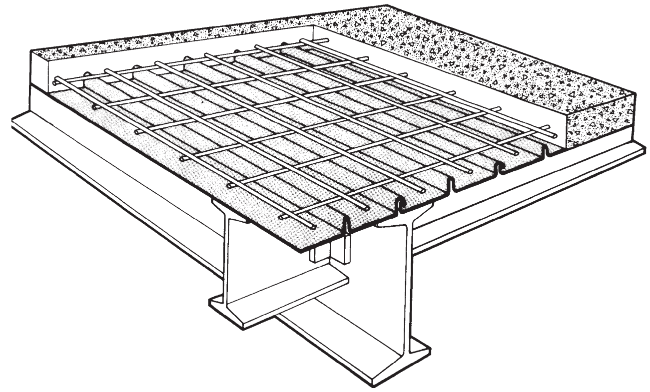


Fig. 5.10 — One type of combined metal decking and reinforcement.

Special Form Systems

Stay-in-place forms become a part of the completed structure. They are often used for concrete floor and roof slabs cast over steel joists or beams, for bridge decks, for a top slab over a pipe trench, or for other inaccessible locations where it is impractical and expensive to remove forms.

These forms are often steel or thin precast, prestressed concrete units that are placed on supporting formwork (when used for floors) and bonded to become the bottom of the concrete element (Fig. 5.9). In some cases, the stay-in-place form is designed to carry some of the loads for which the structure is designed.

Ribbed or corrugated steel decking is used both as a stay-in-place form and as reinforcement (Fig. 5.10). Steel that is intended to provide continuing support or reinforcement should be galvanized. When it acts only as a stay-in-place form (for example, as a top slab over pipe trenches where it is impractical to remove wood forms), the sheet metal can be uncoated ("black") if resulting rust will not cause staining.

The stay-in-place metal forms are secured to the steel or concrete beams and joists by clips or nails attached to the top of the joist, by welding to the steel member, or by casting inserts into the concrete member.

For exterior columns, perimeter beam framing, and wall units on a building below the windows (called spandrels), there is increasing use of decorative precast concrete panels. These serve as a form for the structural member and as the architectural surface finish (Fig. 5.11). These panels can be precast on the site or produced at precasting plants. These sometimes have exposed aggregate surfaces.

Insulating concrete forms (ICF) are stay-in place forms that are assembled as interlocking blocks or sheets. Concrete is placed inside the ICF structure to form flat plates or a grid of concrete (Fig. 5.12). The ICF units then provide an insulation value to the finished walls. Similar

Fig. 5.11 — Precast concrete panels served as column forms, thus creating an architectural surface. During construction, the bases of the columns were protected with wood sheathing held in place with metal straps.

foam forms available for short-span concrete floors.

Slipforms place concrete by extrusion. The concrete is placed in the forms, which are then pulled or jacked vertically or horizontally, extruding the concrete, in the shape of the forms (Fig. 5.13). The most spectacular use of slipforms is for tall towers, silos, elevator shafts in tall buildings, and building walls. The movement of the forms is slow enough for concrete to gain the strength to keep its shape and support its weight.

Vertical slipforms are usually moved by jacks riding on smooth steel rods in the concrete. Horizontal slipforming for such structures as canal linings, highway pavement, drainage channels, curb and gutter, and highway barriers may move on a rail system or shaped beam, or may be accomplished by a self-propelled slipforming machine controlled by a stringline. For either type, the working deck, concrete supply hoppers, and finishers' platforms are carried by the moving formwork.

Slipforming, especially vertical construction, requires an experienced crew and careful, experienced supervision. It requires complete planning of delivery and installation of all embedded items such as dowels, reinforcing, weld plates, and blockouts.

Jump forms are similar to slipforms except that rather than extruding the concrete, the form is "cycled," that is, filled with concrete, stripped, and then "jumped" to the next level after the concrete is set (Fig. 5.14).

These ganged forms may be lifted by crane or self-

Fig. 5.12—Insulating concrete forms (ICFs) are assembled and then filled with concrete. (Photo courtesy of Schwing America Inc.)

raised (electrically or hydraulically). Properly designed, they minimize the number of pieces to be handled and simplify the task of resetting the forms while meeting the tolerances specified.

Form Material and Hardware

Plywood, steel, fiberglass, aluminum alloys, earth, precast concrete, particle board, hard board, gypsum board (for left-in-place subgrade forms), lumber, cardboard, rubber, polyvinyl chloride, and polystyrene are all used for forms and supporting formwork.

To these are added: *form ties*, made from steel, plastic, or fiberglass, to keep forms from spreading under the fluid pressure of the concrete mix; *form anchors*, to fasten forms to previously placed concrete; *form hangers*, to fasten forms to a structural frame of steel or precast concrete; *spacers* or *chairs*, to hold the reinforcing bars the specified distance from the inside surface of the form; *form liners*, to produce a decorative concrete surface; and other accessories such as sleeves, masonry anchorage, and electrical boxes. The type and number of accessories and embedments may at times control the type of forms chosen for the job.

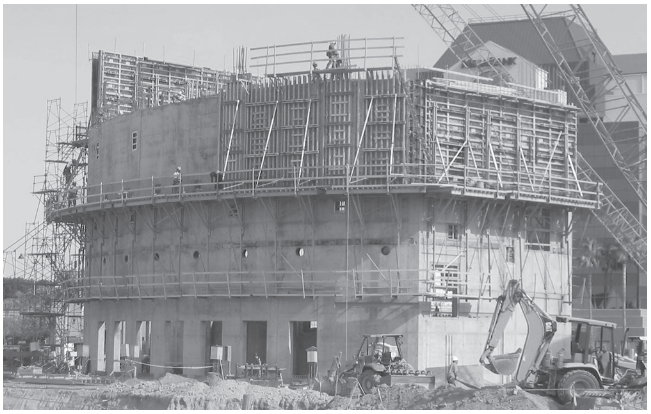


Fig. 5.13 — Slip forms in use. (Photo courtesy of Doka Group.)

Fig. 5.14 — Jump forms in use. (Photo courtesy of PERI Formwork Systems, Inc.)

When forms are built in place on the jobsite, the contractor can use inexpensive materials that are easy to transport, handle, and shape in the field. Any lumber that is straight and structurally strong may be used for formwork. The cheapest grades should not be used because the added labor to work around knots, bark, and twists will offset any material savings, however. Generally, the availability of softwoods such as Douglas fir, western hemlock, and kiln-dried pine make them economical for formwork. Kiln drying reduces excessive warping.

Plywood is widely used for both job-built forms and prefabricated panel systems. Exterior-type plywood (bonded with waterproof glue) is necessary. Plywood should bear the APA trademark (this group was originally the American Plywood Association but is now known as APA—The Engineered Wood Association). And, for that matter, all lumber for formwork should bear the trademark of a recognized lumber-grading agency. Grade B-B plyform, the lowest grade used for formwork, has both faces of B-grade veneer. This is a smooth-sanded solid-surface sheet with repair plugs and small, tight knots permitted. Grade A-C can be used for architectural concrete.

Exterior overlaid plywood is used where smooth, grainless surfaces are wanted. Overlaid plywood (sometimes called plastic-coated) comes as a high-density surface (HDO) or a medium-density surface (MDO). Although overlaid panels are more expensive initially, the total cost of construction can be less with their durability and high-quality finish. For more information on overlaid plywood form panels, refer to the article by Ken Pratt, *Concrete Construction*, February 2004.

Plywood bundles should be strapped and covered with plastic until they are used. Protecting the wood from the elements prevents warping and curling of the panels. Keeping them strapped has the added advantage of reducing theft.

Steel is another important material for formwork. It is used for all steel panel systems, for framing and bracing of wood and plywood panel systems, for steel pans for slab forming, and for stay-in-place forms. Steel vertical shores and structural steel members to frame and support formwork are widely used. Maintain the protective coatings on shoring members, or rust may significantly reduce their load-carrying capacity.

Glass fiber-reinforced plastic forms are available in a variety of pan shapes and can be fabricated to fit complex shapes. Other materials used for pans and void forms include hardboard, fiberboard, and corrugated cardboard.

Plastic laminate form panels are also available. These panels do not absorb water, and result in very smooth formed surfaces.

Double-headed nails, or duplex nails, are useful for nailing kickers, blocks, braces, and reinforcing for wales—wherever nails must be removed when the forms are stripped. Double-headed nails can be pulled easily with a claw hammer or stripping bar without damaging the lumber. Common nails are used in form panels and other components where nails need not be removed in stripping. At times, it is convenient to use finishing nails, which pull through the panel as it is stripped. Box nails are good to attach sheathing to studs or lining materials to form surfaces because their heads leave the smallest impression on the finished concrete.

Form ties are specially fabricated metal or plastic units that hold forms secure against the lateral pressure of freshly placed concrete (Fig. 5.15 and 5.16).

The rod or band-type form tie is commonly used for light construction. The threaded internal disconnecting type is more often used for formwork on heavy construction such as dams, bridges, and heavy foundations. The ties extend between the inner and outer sides of the forms and come with and without devices for spacing the forms a definite distance apart. A holding device on each end of the tie anchors it against the form exterior.

The contractor's form design must include tie details, load capacities, and safety factors. Working loads range from 1000 to over 50,000 lb, depending on factors of safety, kind of steel, diameter of tie, and details of the fastener. The usual safety factor is 2:1; that is, the working load of new ties should be one-half the specified tensile strength.

Tie layout should be planned. Spacing of ties is often kept uniform throughout a wall height for convenience of construction and uniform appearance after stripping. If the tie holes are to be exposed as part of the architectural appearance, tie placement should be symmetrical with the member formed. If tie holes are not to be exposed, ties should be located at rustication marks, control joints, or other points where the visual effect will be minimized.

If appearance is important, use a tie that will not leave exposed metal at the concrete surface. Architectural concrete specifications often require that no metal be left closer than 1-1/2 in. to the surface to avoid rust stains. Job conditions can also affect tie design. For example, installation of ties in a wall might be difficult because of heavy reinforcement or tight working space. To meet such a situation, the number of ties could be reduced to a minimum by selecting heavy ties at wide spacing and designing the formwork to fit this tie requirement.

In stripping forms, some types of ties may be pulled as an entire unit from the concrete after it has hardened. Other ties are broken back a predetermined distance in the concrete at a section of the tie purposely weakened to facilitate "snapping" or unscrewed from a leave-in-place section. Once the tie is removed or snapped off, a small hole remains at the concrete surface. Depending on the architectural treatment specified, these are left open or plugged with mortar (Fig. 5.17). Epoxy mortar or specially manufactured plugs made of mortar, plastic, or metal are also used.

Form anchors are devices used to secure formwork to previously placed concrete (Fig. 5.18). They are embedded in concrete during placement near the top of the lower lift to anchor the bottom of the form for the upper lift. The anchors must have sufficient tensile strength to carry the load of the form and must also have enough embedment in the concrete to develop that holding strength. The length of embedment is particularly important because anchors will often be loaded while the concrete in which they are located is still "green" and has developed only part of its strength. The minimum safety factor, including live loads and impact, is 3:1 for anchors. After the concrete sets, the insert remains in the concrete. The formwork for the next lift is then fastened to the anchor.

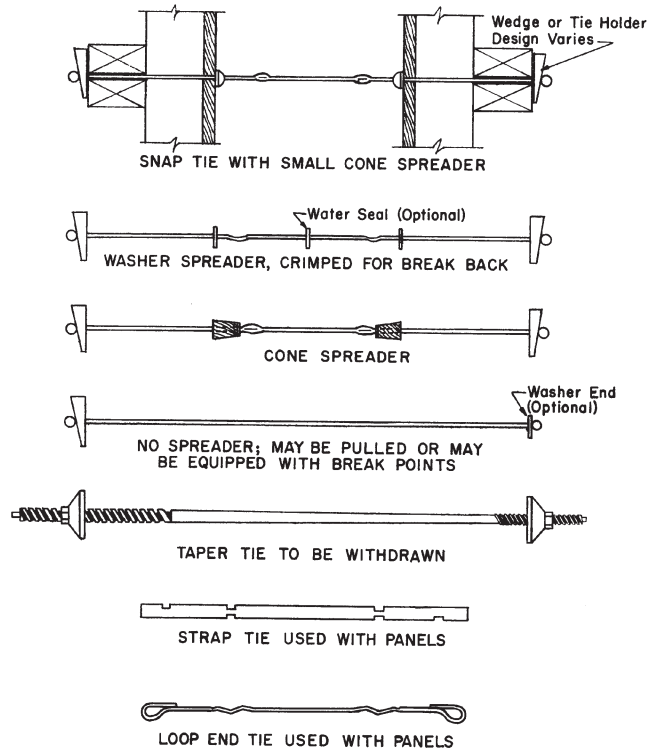


Fig. 5.15 - Some commonly available single member ties. A number of different "wedges" or other devices anchor the tie against the exterior form face.

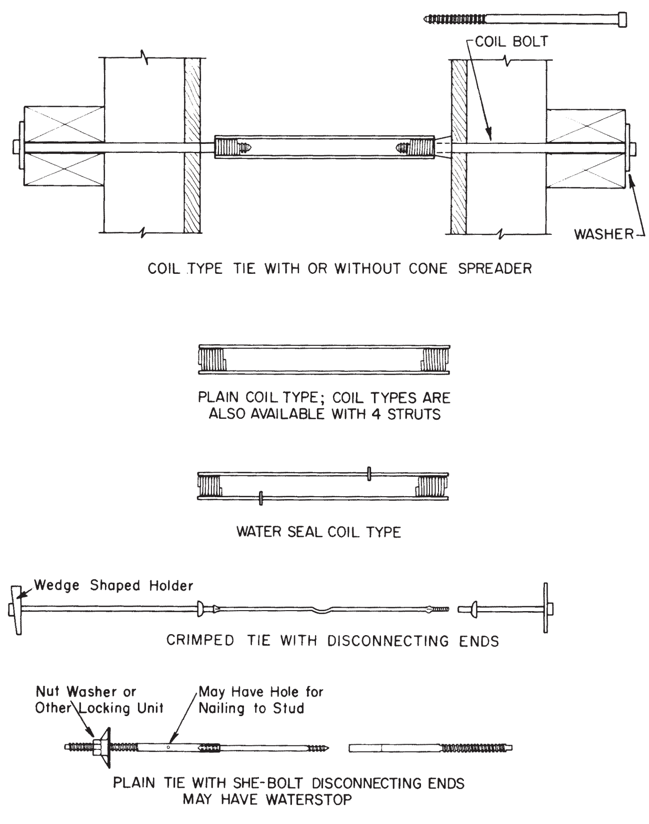


Fig. 5.16 — Some common types of internal disconnecting ties. Either threaded or wedge style holding devices anchor the tie against the exterior form face.

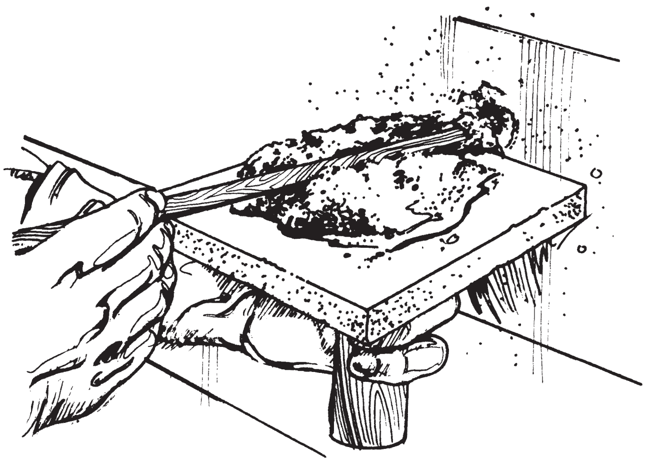


Fig. 5.17 — Stiff mortar is tamped in layers into a hole left by a form tie or bolt. Use a wooden rod to tamp mortar because plastic or steel can cause laminations.

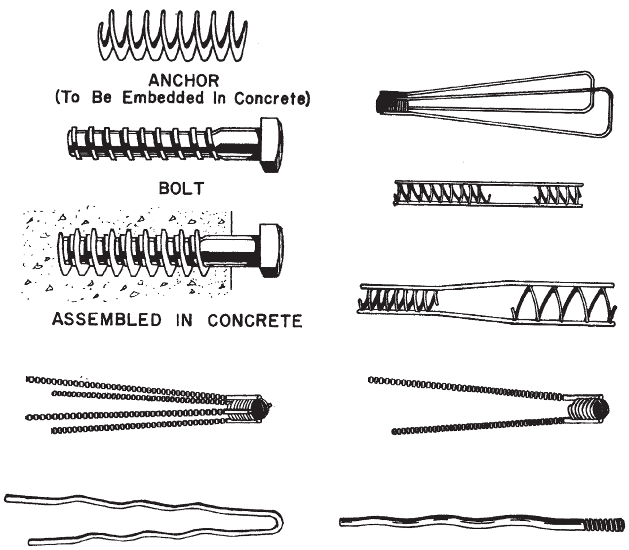


Fig. 5.18 — Various types of form anchors. The screw anchor at upper left shows the bolt and anchor assembly. Other anchors require a variety of bolts or attachments.

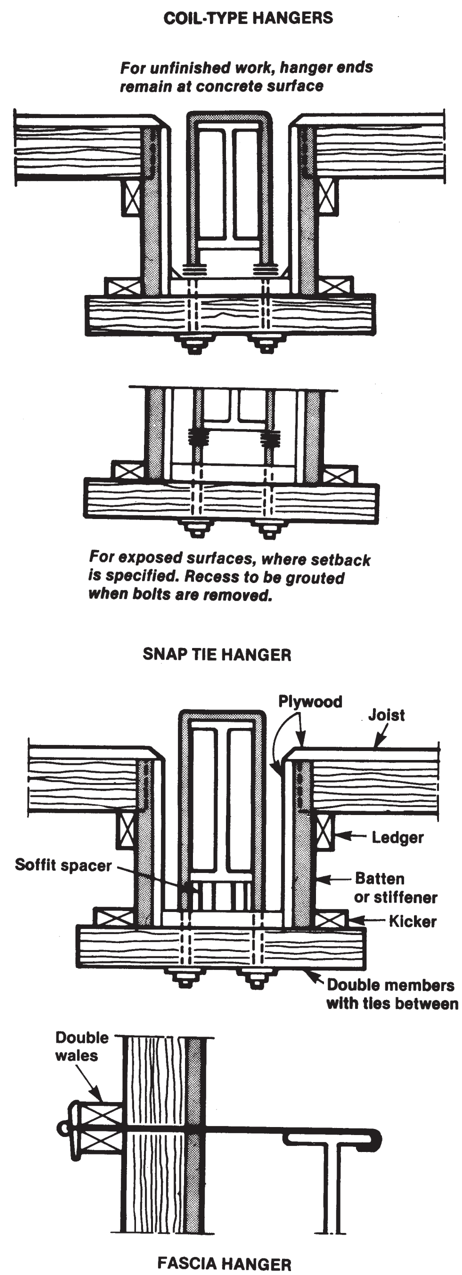


Fig. 5.19 — Typical beam encasement forms showing both coil and snap type hangers.

A number of ready-made devices are available for hanging forms from steel or precast structural members. External holding devices are similar to those used for form ties. Hangers are used for construction of a supported slab or a slab composite with beam framing (Fig. 5.19). The minimum safety factor is 2:1 for form hangers.

In choosing ties or inserts, the initial cost should be balanced with the cost of the labor involved in their installation and form stripping. Wherever the concrete surface is to be visible and appearance is important, the proper type of form tie or hanger that will not leave exposed metal at the concrete surface is essential.

Form Liners

Form liners are used to provide special textures or patterns on concrete surfaces (Fig. 5.20). Some liners are reusable. The costs are fairly high, and preplanning layouts is essential. Careful workmanship is needed to ensure matching patterns on adjacent pours, proper lap of liners, and prevention of concrete leakage.

Stock patterns are available to simulate broken rib surfaces, weathered boards, brick, and other textures (Fig. 5.21). Custom liners made of thermoplastics, thermal setting plastics, elastomers, rubber, and other materials can be molded to produce almost any desired texture or pattern.

Lining materials can be attached to the forms with nails, staples, or waterproof adhesives. When applying sheets of lining material, it is important to start attaching the sheet at its center and work toward the edges to prevent buckling. Hardboard liners should have at least one flat-head nail or staple for every square foot of surface, spaced no further apart then 8 in. on the edges.

Thin form liners, particularly the plastics, expand and contract noticeably with temperature changes. Installing the liners when warm (during the hottest time of the day) will minimize the buckling of the liner and the pulling out of nails or staples. Spraying with cold water before placing the concrete also helps eliminate liner bulges due to expansion.

Because of the texture, use of form liners often requires extra internal vibration of the concrete. The extreme smoothness and imperviousness of some of the linings may make it hard to eliminate air voids, or bug holes, in the concrete surface.

Care should be used in selecting a form release agent (bond breaker). Some liners become so slick that they reject the release agent. Re-refined oils have been known to soften and dissolve thermoplastics and cause elastomers to swell with absorbed oils. To prevent uneven coloring of the concrete, a nonstaining form oil or coating must be used where appearance is important. If there is any doubt about the oil to be used and its effect on either concrete or lining, it should be tested on a sample casting. Suppliers of liners can advise on the best oil or release agent to use.

To avoid the maximum heat of hydration (that can distort the plastic), the best time to strip plastic lined forms is 24 hours after the concrete is placed. With some systems, the forms can be removed with the liner still attached to the concrete; the liner is stripped later. Care must be taken during stripping to protect both the liner and formed surface from damage.

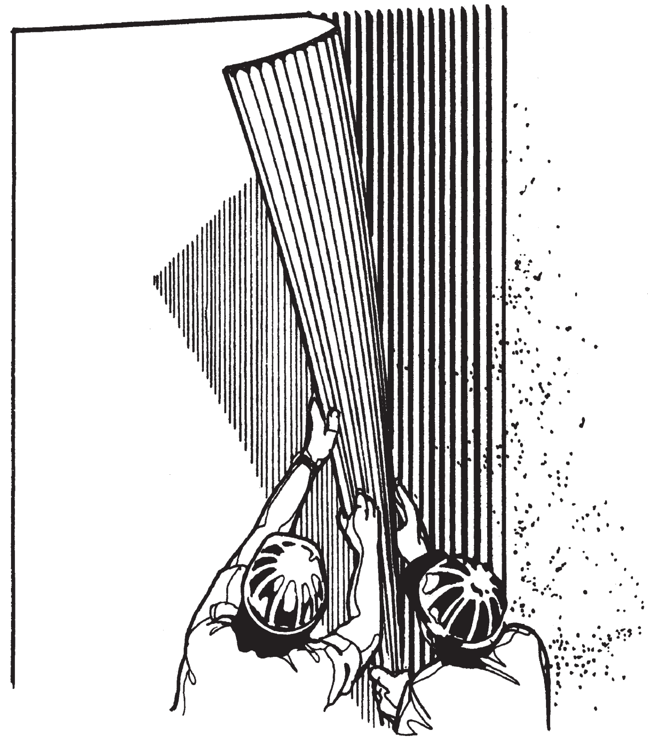


Fig. 5.20 — An elastomeric form liner is peeled away from the concrete, revealing a shallow fractured rib texture. WARNING: If the ribs are deep, the method of peeling shown will spall the concrete. For deep ribs, peel the liner in the direction of the grooves (top-down or bottom-up).

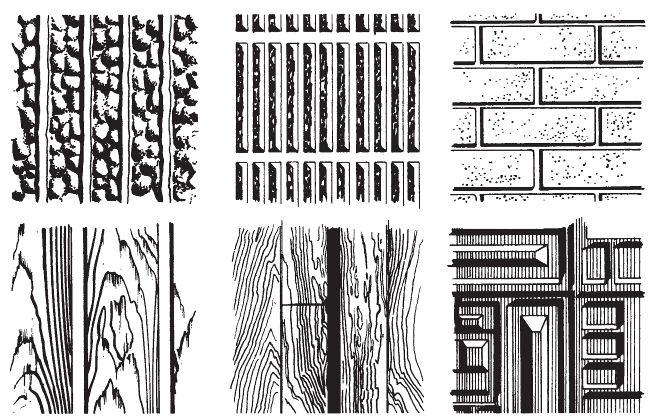


Fig. 5.21 — Form liners offer a variety of textures.

Design of Forms

The concrete contractor usually designs the forms for cast-in-place concrete. A number of form manufacturers also provide specialized form design and prefabrication services. These services are valuable for normal buildings, but are especially valuable for sophisticated form systems such as flying forms, slipforms, and gang form systems.

Often, the concrete contractor is required to submit detailed drawings for the formwork to the project engineer or architect, partly so that the effect of shoring and reshoring on the structure can be checked. Form suppliers will often provide such drawings.

The ideal arrangement is where the contractor or form manufacturer is given an opportunity to suggest to the design engineer how standard forms and methods can result in an economical quality structure. An example of this is in high-rise work where allowable loads might permit columns to vary in size. Although using smaller columns on some upper floors could offer a savings in concrete, it might increase the overall cost of the project because it would probably add to the forming costs as different size forms would be needed, affecting the reuse factor for column formwork.

Along with the drawings and calculations, ACI suggests that the contractor provide full details on design loads and stresses for the formwork, the construction method, concrete placement rates and temperatures, form materials, equipment to be used, and other pertinent information, including the cambers to be built into the form. *Camber* is the amount of upward deflection of the form needed to counteract the downward deflection anticipated when the concrete fills the form and the shores are removed. Camber may also be required by the engineer to compensate for expected deflection of the hardened concrete after stripping the form or for in-service live load. Where the forming system uses threaded or coil loop inserts for form anchors and hangers, the load requirements should be checked.

Usually, the engineer decides the strength of the concrete required before forms can be stripped. But the contractor must also plan how the forms will be removed and how much reshoring of the stripped concrete is required. These plans should be reviewed and approved by the engineer of record to insure the structure's ability to support the formwork and the sequence of stripping and shoring.

It is the contractor, however, who ultimately is responsible for the formwork's ability to hold itself and the concrete in position, and for controlling the finished concrete elements' dimensions within the specified tolerances.

In selecting the formwork system, the contractor wants to consider such things as:

- Safety;
- Available labor skills;
- Availability and type of form material and handling equipment needed;
- If custom forms are to be used, whether rental or purchase is preferable;
- Size of modular units (typically, it's best to use the largest size possible with the lightest weight);
- Number of concrete placements and likely amount of reuse of forms;
- Comparison of hand-setting of forms with gang forming;
- Number of pieces of hardware and miscellaneous items to handle;
- Finish specified for the concrete (which affects selection of ties, form lumber, and form liners);
- Deflection permissible, if specified by the engineer;
- Length of time that forms and shoring must remain in place (cycle time);
- How reshoring is to be handled;
- Form removal;
- Weight of the concrete;
- Carpenter-laborer ratio;
- Cost; and
- Overall project schedule and quantity of materials required to maintain schedule.

Designing formwork is a job concerned with details, such as joint spacing, chamfer strips or grade strips at corners or joints, concrete pads (mud sills) for ground supported shores, working scaffolding, and runways/walkways. Other details are keyways, waterstops, screeds, crushplates for stripping forms so that concrete is not damaged, formwork coatings, openings for mechanical and electrical equipment, and conduits to be buried in the concrete. Use a good grade of form release agent and monitor the results, especially for architectural concrete. If the concrete is to be painted, a check of material compatibility is needed.

The design of the formwork is critically important. Safety of workers is a prime consideration. Concrete is a heavy material, approximately 150 lb/ft^3 for normalweight concrete (more than twice the weight of water). It creates a fluid pressure against the sides of forms that requires great care in design. Frequently, forms are unevenly loaded while concrete is being placed, requiring extra side bracing of elevated forms to avoid sidesway.

One of the most important determinations in form design is the pressure that the concrete will exert on the forms. Although a dozen or more factors could influence the pressure, the three most important variables are:

- Concrete temperature;
- Rate of pour; and
- Weight of concrete.

In late 2001, ACI Committee 347 released an updated formwork standard that provides two pressure formulas, one for walls and one for columns. It also introduced weight and chemistry coefficients, C_W and C_C, which make it possible to apply the formulas to a variety of mixes and concrete weights.

The variables used in the pressure formulas are defined as follows:

p = lateral pressure of concrete in psf (lb/ft^2);
h = depth of fluid or plastic concrete from top of placement to point of consideration, ft;
w = unit weight of concrete, pcf (lb/ft^3);
R = rate of placement, ft/hour;
T = temperature of concrete during placement, °F;
C_W = unit weight coefficient; and
C_C = chemistry coefficient.

For **columns**, the formula used to determine the design pressure is

$$p = C_W C_C [150 + 9000 R/T]$$

with a maximum required pressure of 3000 $C_W C_C$ and a

Table 5.1: Coefficients to be Used in Pressure Equations

Unit weight coefficient C_W	
Concrete weighing less than 140 pcf	$C_W = 0.5\ (1 + w/145)$ but not less than 0.80
Concrete weighing 140 to 150 pcf	$C_W = 1.0$
Concrete weighing more than 150 pcf	$C_W = w/145$
Chemistry coefficient C_C	
Type I and III cement without retarders*	1.0
Type I and III cement with a retarder*	1.2
Other types or blends without retarders* containing less than 70% slag or less than 40% fly ash	1.2
Other types or blends with a retarder* containing less than 70% slag or less than 40% fly ash	1.4
Blends containing more than 70% slag or 40% fly ash	1.4

*Retarders include any admixture such as a retarder, retarding water reducer, or retarding high-range water-reducing admixture that delays the setting of concrete.

minimum of 600 C_W , but never more than *wh.*

For **walls**, the formula is

$$p = C_W\, C_C\, [150 + 43{,}400/T + 2800\, R/T]$$

with a maximum pressure of 2000 $C_W C_C$ and a minimum of 600 C_W, but never more than *wh.*

For purposes of applying the formulas, ACI 347 defines a wall as a vertical element with at least one plan dimension greater than 6.5 ft, and a column as a vertical element with no plan dimension larger than 6.5 ft. Although pressure at any given point within the form varies with time, the designer usually does not need to know the specific variation because the equations indicate the maximum pressure the forms experience.

ACI 347-01 reverts to equivalent hydrostatic head ($p = wh$) when a form is filled to full height in less than the time required for the concrete to begin to stiffen, or for conditions where the coefficients cannot be applied. For example, when forms are filled by pumping from the bottom, ACI 347 recommends using *wh* plus an allowance of at least 25 percent for pump surge pressure. The maximum and minimum pressures given by the formulas do not apply when using $p = wh$.

Table 5.1 gives values of C_W and C_C. Table 5.2 gives base values of lateral pressure on column forms—that is, pressures that can be used when both C_W and C_C are 1. Table 5.3 gives base values for lateral pressure on wall forms—again pressures that can be used directly when both weight and chemistry coefficients are 1. For examples of how to use the tables and formulas, refer

Table 5.2: Base Values of Lateral Pressure on Column Forms,* psf, for Various Pour Rates and Concrete Temperatures

Multiply value from this table by unit weight and chemistry coefficients (see Table 5.1) to obtain pressure for design of column forms.

Rate of placement *R*, ft per hr	Concrete temperature during placement, degrees F					
	90 °F	80 °F	70 °F	60 °F	50 °F	40 °F
1	250	263	279	300	330	375
2	350	375	407	450	510	600
3	450	488	536	600	690	825
4	550	600	664	750	870	1050
5	650	713	793	900	1050	1275
6	750	825	921	1050	1230	1500
7	850	938	1050	1200	1410	1725
8	950	1050	1179	1350	1590	1950
9	1050	1163	1307	1500	1770	2175
10	1150	1275	1436	1650	1950	2400
11	1250	1388	1564	1800	2130	2625
12	1350	1500	**1693**	1950	**2310**	2850
13	1450	1613	1821	2100	2490	
14	1550	1725	1950	2250	2670	
16	1750	1950	2207	2550		
18	1950	2175	2464	2850		
20	2150	2400	2721			
22	2350	2625	2979			
24	2550	2850				
26	2750	3000 $C_w C_c$ maximum governs				
28	2950					

*Base value of lateral pressure equals 150 + 9000 *R/T*
Note: Depending on coefficient values, the minimum of 600 C_w may govern. Do not use pressures in excess of *wh*.

to Mary Hurd's article in the October 2002 issue of *Concrete Construction*.

Forms must be designed for easy, safe removal in a way that permits the concrete to take its load gradually and uniformly and so as to not damage the green (freshly hardened) concrete.

Formwork for post-tensioned slabs must accommodate the forces and movements that will occur when the slabs are tensioned. The steel tendons are pulled to tension levels that, when transferred to the concrete, cause the concrete element to shorten. Forms need to be able to absorb such lateral movement—approximately1 in. per 100 ft.

The post-tensioning steel will often be near the top of the concrete over a support, and near the bottom at midspan between columns or walls. Tensioning may apply downward pressure at beams and other supports,

Table 5.3 Base Values of Lateral Pressure on Wall Forms,* psf, for Various Pour Rates and Concrete Temperatures

Multiply value from this table by unit weight and chemistry coefficients (see Table 5.1) to obtain pressure for design of wall forms.

Rate of placement R, ft/h	Concrete temperature during placement, degrees F					
	90 °F	80 °F	70 °F	60 °F	50 °F	40 °F
1	663	728	810	920	1074	1305
2	694	763	850	967	1130	1375
3	726	798	890	1013	1186	1445
4	757	833	930	**1060**	1242	1515
5	788	868	970	1107	1298	1585
6	819	903	1010	1153	1354	1655
7	850	938	1050	1200	1410	1725
8	881	973	1090	1247	1466	1795
9	912	1008	1130	1293	1522	1865
10	943	1043	1170	1340	1578	1935
11	974	1078	1210	1387	1634	
12	1006	1113	1250	1433	1690	
14	1068	1183	1330	1527	1802	
16	1130	1253	1410	1620	1914	
18	1192	1323	1490	1713	2000 $C_w C_c$ controls	
20	1254	1393	1570	1807		

* Base value of lateral pressure equals 150 + 4300/T = 2800 R/T

Note: Maximum pressure is 2000 $C_w C_c$ and minimum is 600 C_w. Do not use design pressures in excess of wh.

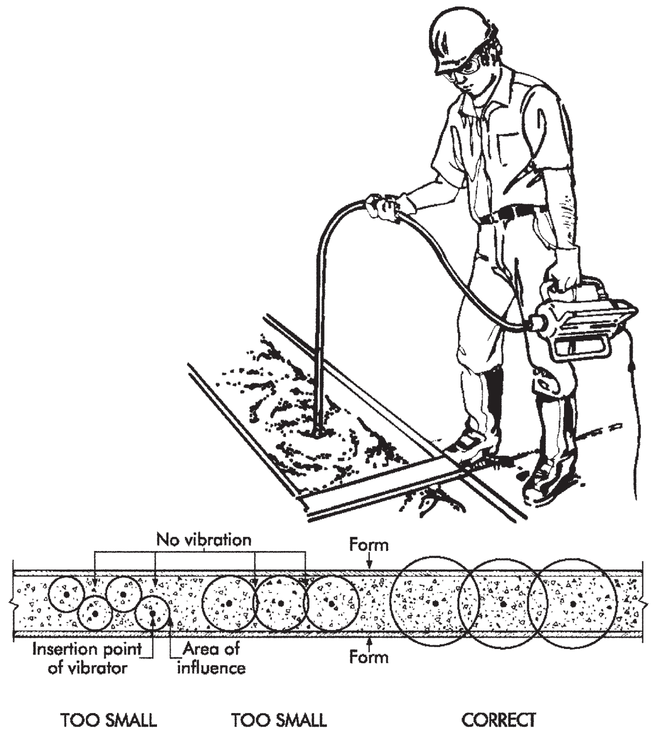


Fig. 5.22 — An internal vibrator causes the concrete within its field of action to act like a thick liquid and thus consolidate better. An internal vibrator should be lowered into the concrete vertically and slowly withdrawn.

and upward forces at midspan. Formwork, shoring, stripping patterns, and reshoring must be designed with these forces in mind. It is important to be aware of these forces when attaching subsequent form materials like shoeplates for wall forms.

Placing Concrete in the Forms

Before concrete placing begins, formwork must be inspected to see that it is in the correct location, at the correct elevation, and built so that it will produce the required finish and dimensions with adequate safety. Any foreign material must be removed from the forms.

Make sure that wall ties and connection hardware are correctly installed. One missed form tie can cause a form to bulge or fail. Remember that the concrete faithfully takes the shape of the form. If the form bulges, the contractor may have to grind it out. One missed connection can be very costly to replace in hardened concrete.

The concrete should be placed at or as near as possible to its final position in the forms. Do not dump the concrete in piles and move it into position with the vibrator. Excessive movement of concrete within the forms results in segregation and poor consolidation (the sand-cement paste flows ahead of the coarse aggregate).

The stream of concrete filling the form for columns, walls, and beams should not be allowed to separate paste from aggregates by permitting it to fall freely over ties, spacers, rebar, or other embedded items. Concrete should seldom be dropped over 5 ft without using a drop chute (elephant trunk). The drop chute should be lowered between wall reinforcing to avoid segregation in the concrete. When rebars are extremely congested, mixes specifically designed to prevent segregation can be used and dropped further.

Freshly mixed concrete must be properly consolidated after it is deposited into the form if it is to achieve its desired material properties. Proper consolidation reduces or eliminates rock pockets and honeycomb and ensures that each fresh layer of concrete is consolidated with the layer below. The preferred method of consolidation is vibration. External vibrators are attached to the formwork and internal vibrators that are hand held and inserted into the concrete (Fig. 5.22). The use of external form vibrators requires special form design to determine the power output and location of the vibrators because external vibration can destroy a form that is not designed for such loading.

The freshly placed concrete behaves temporarily like a fluid, creating a hydrostatic pressure that pushes against the vertical forms. The rate of placing (average rate of rise of the concrete in the form) has a primary effect on lateral pressure. With slower rates of placing, concrete at the bottom of the form begins to harden, and the lateral pressure is reduced to less than full fluid pressure by the time concreting is completed in the upper parts of the form.

The rate of concrete placement in vertical forms should be such that the form design pressure is not exceeded. This is important! More than 10 times the cost of accurately designing a form can be lost if the concrete is placed so quickly that the form is seriously overloaded.

The form for a drop spandrel beam tends to bend outward between columns. Provide some means (such as a cable and turnbuckle) to adjust the vertical form back into alignment if necessary.

Temperature is also important, especially in cold weather. The concrete sets more slowly in cold weather, and this will reduce the permissible rate of placement and increase the time until forms can be stripped. It also affects the shoring and reshoring sequence.

Unanticipated loads on multistory floor slab formwork are often overlooked and lead to form sagging or even to failure. Some examples of unanticipated loads are: placing concrete in a concentrated area, impact loads from dropping concrete from an excessive height into the form, and stockpiling reinforcing bars in one spot.

One of the most dangerous periods in a construction project is when the concrete is being placed in the form. Personnel must be especially aware of abnormally high deflection or form movement during concreting that might warn of impending collapse.

Formwork should be continuously watched during and immediately after concreting. Precautions must be taken to protect formwork watchers and maintain a safe area (and exit route) during concreting. Telltale devices such as string or wire lines enable form watchers to constantly check elevations, camber, and plumbness.

Although the most critical stage has passed once the concrete has been placed, the form watchers should remain on duty until the concrete has been floated and telltale devices show that deflection has ceased. Gradually increasing deflection in the form is often a warning of an impending failure.

If any serious weakness develops during the concreting that would endanger workers or cause undue distortion of the structure, work must be halted while the formwork is strengthened.

Maintenance of Forms

To increase plywood forming panel longevity, regular maintenance—both before and after the placement of concrete—is important. If edge sealer is not mill-applied to new plywood form panels, it is important to apply a top-quality edge sealer before the first pour. Forming panels start to swell at the edges due to absorption of moisture. Seal any cut edges with two coats of polyurethane paint or varnish.

The use of metal bars or pries when stripping plywood forms may damage the panel edge and surface, especially a textured surface. Instead, crews should use wood wedges, tapping gently when necessary.

Soon after being removed, plywood forms should be inspected for wear and cleaned with a hardwood wedge and a stiff fiber brush rather than a metal brush, hammer, or claw hammer. They should then be repaired, spot-primed, refinished, and lightly treated with a form-release agent before reusing.

After crews strip and clean the forms, the panels can be stacked faces together to slow the drying rate and minimize face checking (hairline cracks on the face ply). Plywood panels should be stored out of the sun and rain and covered loosely to allow air circulation without heat buildup. For transporting, the forms should be carefully piled flat, face-to-face and back-to-back. Proper upkeep and repair can ensure a longer service life and a stronger formwork structure.

Form-Release Agents

With the many different form-release agents available, contractors are faced with the difficult task of sorting out which product is best for their specific requirements. The factors to consider when selecting a form-release agent include concrete appearance, concrete paintability, environmental issues, employee safety, transportation, jobsite storage requirements, and desired plywood durability.

Form-release agents, which are often referred to as form oils, come in two basic categories: barrier types and chemically reactive types. Barrier types function by creating a physical barrier between the plywood form and the freshly placed concrete in the same way that butter prevents cookies from sticking to a cookie sheet. Diesel oil, heating oil, recycled motor oil, and lubricating oil are some of the more common ingredients found in barrier-type form-release agents.

Chemically reactive form-release agents contain some type of fatty acid (the active ingredient), which reacts with the free lime in fresh concrete to form a metallic soap that is not soluble in water. This soap becomes the releasing mechanism for the plywood panels and makes the faces of plywood or overlaid plywood panels more water-resistant and thus helps protect them from the alkalis in fresh concrete, increasing plywood durability.

Both B-B and MDO panels will readily adsorb most chemically reactive release agents. HDO panels, on the

TYPICAL TOLERANCES FOR VARIOUS ELEMENTS

FOOTINGS

Variation in length and width	–1/2 in., +2 in.
Location misplacement or eccentricity	2 percent of the footing width in the direction of misplacement, but not more than 2 in.*
Reduction in thickness	–5 percent of specified thickness

*Applies to concrete only, not to reinforcing bars or dowels. Plus (+) tolerances are larger for unformed footings.

WALLS

Variation from the plumb should not be more than ±1 in. for structures up to 100 ft high.

Variation from the plumb of conspicuous lines such as control joints should not be more than ±1/2 in. for walls up to 100 ft high.

Variation in the size of wall openings should not be more than –1/4 in. or +1 in.

Variation in wall thickness is limited to:

- –1/4 or +3/8 in. for walls 12 in. thick or less
- –3/8 or +1/2 in. for walls 12 to 36 in. thick
- –3/4 or +1 in. for walls over 36 in. thick

COLUMNS

ACI 117 gives tolerances for completed structures; such tolerances give the form builder guidances as to the level of accuracy required in forming concrete columns. Variations of 1 in. from plumb are permitted for structures up to 100 ft high. Variation in cross sectional dimensions is limited to:

- –1/4 or +3/8 in. for thickness 12 in. or less
- –3/8 or +1/2 in. for thickness 12 to 36 in.
- –3/4 or +1 in. for thickness over 36 in.

BEAMS AND GIRDERS

Beam and girder forms should be built to ensure completed work within the specified tolerances for completed construction. In the absence of other stated tolerances, the recommendations of ACI Committee 117 may be followed for building construction. These include the following:

Variation from the level or from the specified grade for beam soffits before removal of shores should not exceed ±3/4 in.

Variation from level or specified grade for exposed parapets should not exceed ±1/2 in.

Deviation from cross section dimensions should not exceed:

- –1/4 or +3/8 in. for thickness less than 12 in.
- –3/8 or +1/2 in. for thickness from 12 to 36 in.
- –3/4 or +1 in. for thickness more than 36 in.

ELEVATED SLABS

In the absence of other contract provisions, slab forms should be built to produce slabs meeting ACI 117 tolerances. These requirements include:

Elevation of formed soffit before removal of shores not more than ±3/4 in. from specified elevation.

Variation in slab thickness:

- –1/4 or +3/8 in. for thickness less than 12 in.
- –3/8 or +1/2 in. for thickness from 12 to 36 in.
- –3/4 or +1 in. for thickness more than 36 in.

Variation in size of openings not more than –1/4 or +1 in.

From *Formwork for Concrete*, SP-4, Sixth Edition, by M.K. Hurd, American Concrete Institute, 1995, 500 pp. For more details, consult ACI 117 and 117R.

other hand, will not. Therefore, it is always a good idea to use a reactive release agent that dries and will not be removed by rain showers. Non-drying reactive release agents generally do not have good rain resistance prior to concrete placement, and they tend to collect dust and will create a slippery work environment when used on horizontal forms.

Chemically reactive release agents typically cost more per unit volume than barrier-type release agents; however, they are usually applied at a considerably lesser rate and almost always have a lower cost per unit area. This benefit, in addition to increased plywood durability, makes chemically reactive release agents a wise choice for plywood and overlaid plywood concrete form panels.

Although forming panels are typically treated with form-release agents at the mill, unless the mill treatment is reasonably fresh when the panels are first used, they may require another treatment of release agent before the first use. Even an MDO should be treated with a chemical release agent prior to first use and between each pour. For reused panels or new panels not freshly mill-treated, application of a thin film of form release agent will prolong the life of the plywood forming panel, enhance its release characteristics, and minimize the potential for staining the concrete. For best results, apply the release agent a few days before using the forms.

Tolerances

Very early in the construction process, the contractor should ask the engineer for any information that is not provided in the contract documents and should clarify any ambiguous wording in the specifications so that the design intent is clearly understood. Tolerances must be clear and reasonable so that the forms are built properly.

Job tolerances are specified for form dimensions, as well as for variations from plumb, variations from level, camber, and the dimensions between walls or columns.

The contractor must pay special attention to the specifications for variation from plumb and grade. (Grade is the elevation or distance above some reference point.) These tolerances are important because out-of-plumb or out-of-grade concrete elements can create unanticipated lateral loads on the structure and connection problems.

The architect-engineer specifies the amount and shape of camber desired to compensate for deflection of the finished structure. Camber is a slight upward curvature intentionally built into a structural element or form to improve appearance or to compensate for deflection of the element under the effects of loads, shrinkage, and creep.

Forms must be built to provide compensation for both anticipated deflection and settlement of the formwork and anticipated dead load and creep deflection of the finished structure. A common rule of thumb is to camber 1/4 in. per 10 ft of span to take care of form deflection movements.

The contractor is expected to set and maintain forms to insure that the completed work conforms to the camber and slab thickness specified by the engineer within the tolerance limits specified.

The contractor should monitor form elevations to be sure that desired camber is maintained. Adjustments should be made promptly by jacking and wedging before the concrete is placed. Use tag lines and form watchers to closely monitor the concrete placement. If forms move out of vertical or horizontal alignment, they can be re-aligned while the concrete is still plastic.

Tolerances in the concrete forms reflect the engineer's desire for precision, but also have associated costs. Very close tolerances will increase the structure's cost. This should be reflected in the contractor's bid.

Tolerances that are too broad, however, can lead to other problems. For example, if cast-in-place columns and spandrel beams are to support a precast, prestressed double tee or hollow-core slab, the distance between the two spandrel beam ledges has to be reasonably accurate. If not, the double tees made in the precaster's factory before the spandrel beams were cast may be too long and have to be cut. This will be costly. Even worse, however, if they are too short and the specified bearing area is reduced, new tees may have to be produced.

Similarly, if the forms are built larger than needed, the extra concrete adds to the cost, and the added weight of the extra concrete can be significant. If flat plate, high-rise building floors are designed to be 6 in. thick but are cast 6-1/2 in. thick, there will be an 8 percent increase in weight. For a flat plate floor with a 25 x 25 ft column spacing, this excess thickness would add 3750 lb per bay to the column load per floor. In a 50-story building, this would be 187,500 lb per bay for the full building weight.

On the other hand, an increase of 1/2 in. in the thickness of a slab on ground will have little effect on the slab, but it will increase the amount of concrete used and the cost.

The same care is needed to assure that formwork shores are plumb and cross-braced, and remain plumb under the loads that will be applied to the forms under the procedures selected for concreting.

Concrete buildup on forms may affect tolerances. For example, modular forms that are used repeatedly without cleaning may "grow" because of increased buildup of concrete on the edge of the forms. When used side-by-side along a wall, it is not uncommon to see such forms grow an inch over the wall length. It is best to always clean forms immediately after stripping and before reusing. Green concrete paste is much easier to remove than the hard, dry material.

During and after concreting, the contractor should continue to check form dimensions, elevations, and tolerances. For example, in suspended slabs, check tolerances before concreting and before stripping floor slab forms.

Cost of Formwork

As noted at the beginning of this chapter, the cost of formwork is 35 to 60 percent of the cost of the concrete work in a structure. By working closely with the engineer, the contractor can devise ways to reduce formwork costs.

The design of cast-in-place structures should be approached much like a precast structure. In both cases, standardization minimizes cost. If the designer calls for dimension changes from beam to beam, it will significantly increase formwork costs. Whenever the opportunity arises, the contractor should alert the designer to situations where a reduction in material quantities will not be efficient since it will result in increased form costs.

The designer should also recognize the needs of the electrical, mechanical, and structural systems for openings through the structure to minimize complicating the formwork with special openings for each system. Openings through formed surfaces should be minimized.

The contractor must spend the time necessary to fully plan the formwork and develop a clear understanding of how to carry out the work. Working or "lift" drawings may be necessary. A primary aim is to reduce the carpenter's on-site labor in form fabrication, setting, and stripping. The contractor needs his engineer to review formwork plans and drawings to assure compliance with the contract and especially to increase safety.

For pan joist and waffle slab systems, the designer can bypass the need for special forms and shoring by keeping the depth dimension standard. Costs can also be reduced if the designer makes column widths and beam widths the same (or beams wider) to reduce the complexity of forms where the two meet.

Table 5.4 — General Guidelines for Form Stripping Times (in the Absence of Engineer-Specified Strength or Time)

Walls	12 hours	
Columns	12 hours	
Sides of beams or girders	12 hours	
Pan joist slabs 30 in. wide or less Over 30 in. wide	 3 days 4 days	
Post-tensioned slabs	When fully tensioned	
Joist, beam, or girder bottoms	Where design live loads are:	
	< dead load	> dead load
Under 10 ft clear span	7 days	4 days
10 to 20 ft clear span	14 days	7 days
Over 20 ft clear span	21 days	14 days
One-way floor slabs		
Under 10 ft clear span	4 days	3 days
10 to 20 ft clear span	7 days	4 days
Over 20 ft clear span	10 days	7 days
Two-way floor slabs	Contingent on reshores (where required) being placed immediately after stripping. Where reshores are needed to minimize sag or creep (rather than for distribution of construction loads on the slab), shore capacity and spacing must be set by an engineer.	

Form Removal

The designer and contractor can have conflicting goals over when to remove forms. The designer wants the maximum strength gain, while the contractor wants to strip and reset (cycle) forms as soon as possible to improve the schedule and maximize form reuse.

Forms can usually be removed when the concrete is strong enough to carry its own weight and any construction loads it will have to support without deflection beyond specified limits. The engineer should specify the minimum concrete strength to be attained before removal of forms or shores.

Forms for walls and columns can usually be stripped much earlier than forms for beams and elevated slabs. A common specification for walls and columns is 12 hours after concrete placement is complete. Forms are normally designed for gradual form removal to minimize shock or impact loads. Dropping forms or slamming panels against the finished work costs the contractor time and money. **Special precautions must be taken with cantilevered forms.** Cantilevered elements often need longer curing before stripping the forms—sometimes as long as 28 days—because of the higher strength requirements of these elements.

Measuring Concrete Strength for Form Removal

When is the concrete strong enough to remove the forms? The strength gain of concrete depends on the type of cement and admixture used, the concrete's temperature when placed, and the temperature and time between casting the concrete and the time of form removal. (The size of the member also can affect its temperature.)

Theoretically the concrete strength can be measured by breaking cylinders that were made at the same time the concrete was placed and that were cured under conditions similar to the actual concrete beam or slab. Ideally, the cylinders are cured under the same conditions as that portion of the member that is cured under the poorest conditions.

But cylinders are seldom the same thickness as the concrete element, and the insulation provided by a wooden form would be difficult to approximate. Nevertheless, cylinders are the most-used method for measuring concrete strength.

However, there are other methods, including "nondestructive" testing. Computer programs based on all factors affecting strength gain can provide an estimate of strength at any given time, and strength can be measured in ways other than cylinder testing:

Rebound uses a spring driven hammer that correlates concrete strength to the rebound of the hammer from the concrete surface.

Pullout measures the force required to pull out a metal insert that has been embedded in the concrete, and correlates that force to concrete strength.

Penetration measures the resistance of the concrete to penetration of a steel probe, and correlates it to concrete strength.

Maturity meters measure the temperature of the concrete over a period of time to calculate the strength. Refer to the more-detailed description of maturity meters in the Chapter 2 section, "Compressive Strength Tests (ASTM C 31 and C 39)."

For these methods, a correlation between the measured property and strength should be established prior to field testing.

Time as a Measure of Strength for Form Removal

ACI's "Guide to Formwork for Concrete" (ACI 347R) recommends that engineer-specified criteria based on strength gain be used to determine form removal time. In the absence of such criteria, the guide contains recommendations for the length of time that formwork should remain in place when the air temperature is above 50 F (Table 5.4). The time need not be consecutive, but it is the total time during which the temperature is above 50 F.

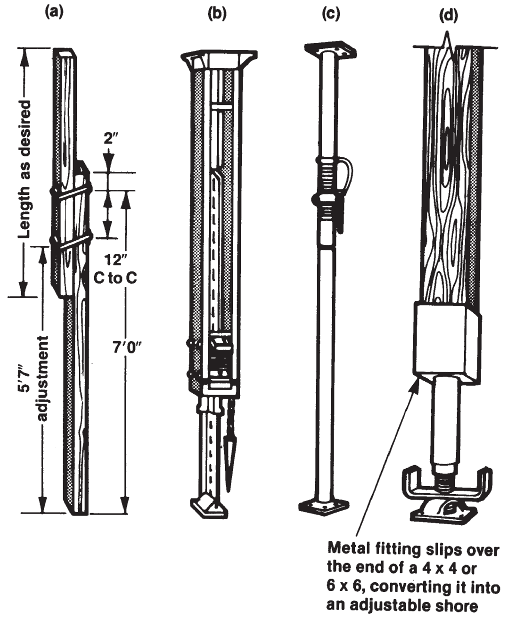


Fig. 5.23 — Single-post shoring.

Fig. 5.24 — Tubular welded frame shoring. (Photo courtesy of Doka Group.)

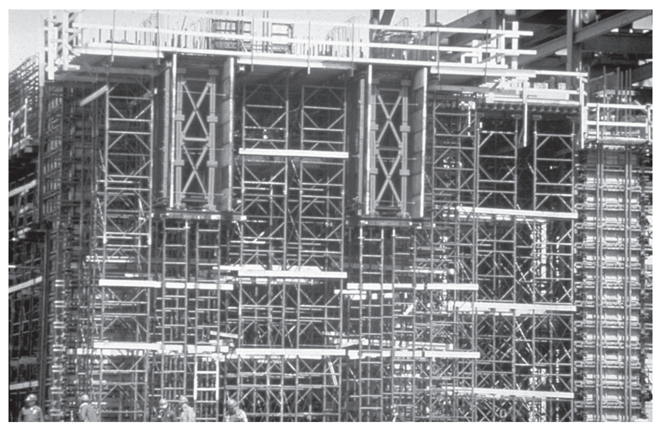


Fig. 5.25 — Shoring systems are available in a wide range of models and sizes for almost any concrete support application. (Photo courtesy of Symons Corp.)

When high-early-strength cement is used, these times can be shortened. When air temperatures remain below 50 F or retarding admixtures are used, these times should be lengthened. Unusually heavy construction loads may require longer times before form removal. Some new concrete mixes are available that require twice as much cure time before stripping forms than standard or high-strength mixes from the past. The contractor should watch concrete purchase specifications carefully when these new mixes are used. Though these mixes might cost less, the construction schedule may not allow the extra time needed for strength gain.

Shoring and Reshoring

Shores are vertical (or sometimes sloping) posts or props (Fig. 5.23) that carry the weight of forms, formwork, concrete, and construction loads from the form to the first supporting surface below—either the ground or one or more floors. There is also ladder-type scaffold shoring (Fig. 5.24). Adjustable beams and trusses that support formwork over a long span and eliminate intermediate vertical shores are called horizontal shores.

The shores and reshores (shores that are reinstalled after form removal) have to support all anticipated loads with sufficient factors of safety to avoid collapse. The entire shoring, form removal, and reshoring system must be thought through and planned for maximum efficiency and safety and then designed to determine specific member sizes.

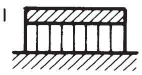
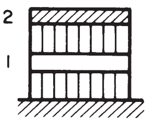
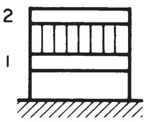
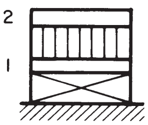
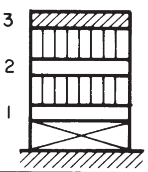
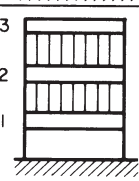
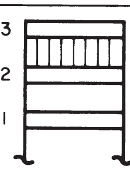
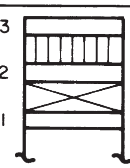
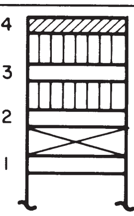
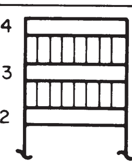
Do not remove reshores until the slab or beam supported has reached the strength required to support the loads on the member. Unless the removal of reshores is carefully planned, loading on parts of the structure will be unbalanced, creating unanticipated stresses.

Costs are lowered when it is possible to strip the forms before the concrete has reached its full design strength. If the shores are pulled out too early, however, the concrete may not be able to support its own weight and the weight of any construction materials or operations. The concrete is reshored so that work can begin on the supported floors or beams.

Reshores are placed so that the slab or beam is supported but not lifted above its specified position. Wedges or jacks are used to make slight adjustments.

Table 5.5 — Simplified Analysis of Loads on Shores and Slabs of Multistory Structure. Two Levels of Shoring, One of Reshoring (Construction Live Load and Weight of Formwork Not Included. D = Weight of Slab)

RIGID SUPPORT AT STARTING LEVEL — FRESHLY PLACED SLAB — HARDENED SLAB — STORY OF SHORES — STORY OF RESHORES

STEP NUMBER	OPERATION AND REMARKS	STATUS OF STRUCTURE	LOAD CARRIED BY SLAB, IN MULTIPLES OF D.			SHORE LOAD AT END OF OPERATION
			AT BEGINNING OF OPERATION	CHANGE DURING OPERATION	TOTAL AT END OF OPERATION	
1.	Place Level 1 concrete; full load transmitted by shores to ground.	1 	0	0	0	1D
2.	Place Level 2 concrete; all load goes thru shores to ground since Slab 1 can't deflect and pick up load.	2 1 	0 0	0 0	0 0	1D 2D
3.	Remove first level shores; shore load of 2 D is divided equally between two slabs. In this case, each one takes its own weight.	2 1 	0 0	+1D +1D	1D 1D	0
4.	Place reshores snug but not loaded. This causes no change in other slab or shore loadings.	2 1 	1D 1D	0 0	1D 1D	0 0
5.	Place Level 3 concrete; all new load is carried to ground by shores and reshores. Slabs can't deflect further and therefore don't pick up any of the new load yet. Slabs 1 and 2 continue to carry their own weight.	3 2 1 	0 1D 1D	0 0 0	0 1D 1D	1D 1D 1D
6.	Remove first floor reshores. The three slabs will deflect together. Reshore load is then divided equally among the three interconnected slabs. Remaining shores carry that portion of the load above them not carried by the slabs.	3 2 1 	0 1D 1D	+0.33D +0.34D +0.33D	0.33D 1.34D 1.33D	0.67D 0.33D
7.	Remove shores under Slab 2. Load formerly carried by those shores is divided equally between two remaining interconnected slabs.	3 2 1 	0.33D 1.34D 1.33D	+0.17D +0.16D −0.33D	0.50D 1.50D 1D	0.50D
8.	Reshore beneath Slab 2. Reshores act as struts. Slab loads remain unchanged.	3 2 1 	0.50D 1.50D 1D	0 0 0	0.50D 1.50D 1D	0.50D 0
9.	Place Level 4 concrete. Its load is distributed equally among three interconnected slabs below.	4 3 2 1 	0 0.50D 1.50D 1D	0 +0.33D +0.33D +0.34D	0 0.83D 1.83D 1.34D	1D 1.17D 0.34D
10.	Pull reshores beneath Level 2. The 0.34 D load in reshores is divided equally among three remaining interconnected slabs.	4 3 2 	0 0.83D 1.83D	+0.11D +0.11D +0.12D	0.11D 0.94D 1.95D	0.89D 0.95D

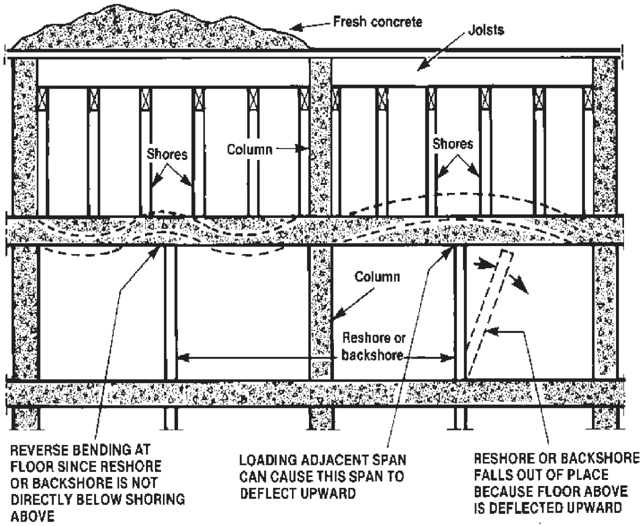


Fig. 5.26 — Improper positioning of shores from floor to floor may create bending stresses for which the slab was not designed. If reshores or backshores do not match shores above, stresses would need to be recalculated by the form designer. Reshores and backshores must be prevented from falling.

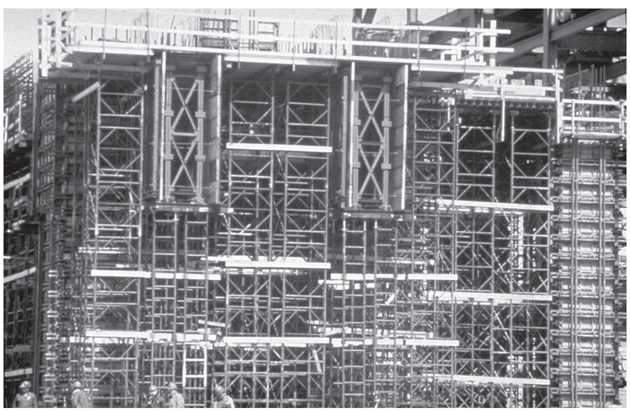


Fig. 5.27 — Types of forms for slabs on ground.

When placing shoring on slabs, the shores should be located directly above any shores or reshores below. In a multistory building, reshores can extend over many floors transferring load to several lower floors (Fig. 5.25). Reshoring is an alternative to permanent shoring that remains in place during and after formwork removal. Both methods have advantages and disadvantages.

Reshoring is one of the most danger-prone parts of cast-in-place concrete construction. For multistory construction it is complex, requiring engineering studies to avoid overloading any of the lower floors because they pick up the major share of the load-carrying responsibility.

No additional loads or construction should occur on the floor being reshored until the reshoring operation is complete. Care should also be taken to assure that stress reversals are not created (Fig. 5.26). For example, if you jack up the center of a floor above the level it was in the form, the top of the slab will go into tension, for which it was not reinforced, leading to cracks. Shores have been known to punch through a thin flat plate floor at points where reinforcing bars are widely distributed. At locations where shores could punch through the concrete, bearing plates of steel are placed at the ends of shores to spread the load over a larger area of concrete.

Table 5.5 illustrates how loads develop in the slab, shores, and reshores of a three-story flat-slab building. The first two slabs are placed without removing any shores, and the load is transmitted directly to the ground. The slabs carry no load until the first level of shores is removed, and each then bears its own weight. As the cycle proceeds, when a level of reshores or shores is removed, the shore force is distributed equally among the slabs in the system. It should be emphasized that reshores are installed snug, but not tight. Positive means must be used to assure that reshores do not fall out as other parts of the slab move when loads are redistributed.

The design of the formwork and reshoring should be handled by a professional engineer who determines if the structure can safely support the loads based on the construction sequence selected, and approved by the structural engineer of record.

Formwork for Slabs-on-Ground

Forms for the construction of slabs-on-ground are relatively simple compared with formwork for suspended slabs (Fig. 5.27). In general, there are edge forms and forms placed around columns that isolate the main slab from any differences in settlement that may occur between the floor slab and the concrete around the column above the column footing.

Boards or metal panel forms are commonly used for edge forms. Metal or flexible plastic forms are available from a number of suppliers in various standard or custom depths for both straight and cured form requirements. They are held in position by stakes or proprietary support systems. Crossforms or bulkheads may be placed where joints are to occur. Stay-in-place key forms are often used to form these intermediate joints.

Forms for strip footings are similar to slab-on-ground forms. Fabric forms for footings have been developed as have combination drainage boards and side forms.

All of these forms should be stiff enough to take the lateral movement of manual or vibrating screeding (screeding is the act of striking-off the concrete to form a smooth plane surface) and be staked to the subgrade with stakes at close enough centers to hold the forms straight and in place. Be sure to drive down the stakes below the top of the edge form. This will allow the top strike-off screeds, edge tools, and finishing machines to freely pass over the top edge without obstruction.

Screeds are the devices that provide the means of striking off the surface of the concrete slab to the grade specified. Screeds can be wood, pipe, precast concrete, T-bars, or "wet screeds" that are rows of concrete placed to grade to stay in place.

Want to Know More?

This chapter offers merely an introduction to the subject of forms and formwork. Contractors and others involved with (or interested in) formwork should get a copy of the American Concrete Institute's "Guide to Formwork for Concrete" (ACI 347R) for a ready reference on formwork design, construction, shoring, and reshoring. Readers are also encouraged to obtain the other publications listed that discuss formwork design and construction in great detail.

ACI Committee E 703, "Cast-in-Place Walls (CCS 200)," American Concrete Institute, Farmington Hills, Mich., 2000, 102 pp.

ACI Committee E 703, "Concrete Formwork (TB2)," American Concrete Institute, Farmington Hills, Mich., 1998, 12 flyers.

ACI Committee E 703, "Supported Beams and Slabs (CCS 3)," American Concrete Institute, Farmington Hills, Mich., 1989, 100 pp.

ACI Committee 347, "Guide to Formwork for Concrete, (ACI 347R)," American Concrete Institute, Farmington Hills, Mich., 2001, 32 pp.

Concrete Forming, Design/Construction Guide, APA The Engineered Wood Association, free download at www.apawood.org

Cordova, B., and Desler, F., "Plywood Understood," *Concrete Construction*, January 2003.

Hurd, M. K., *Formwork for Concrete*, SP-4, Sixth Edition, American Concrete Institute, Farmington Hills, Mich., 1995, 500 pp. (This book includes the ACI 347 report in an appendix.)

Hurd, M., "Pressure on Wall and Column Forms," *Concrete Construction*, October 2002, pp. 43-47.

Koel, L., *Concrete Formwork*, American Technical Publishers, Inc.

Pratt, K., "The Many Faces of Overlaid Plywood Form Panels," *Concrete Construction*, February 2004, pp. 66-72.