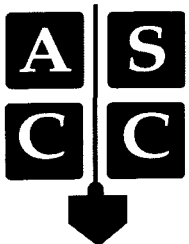
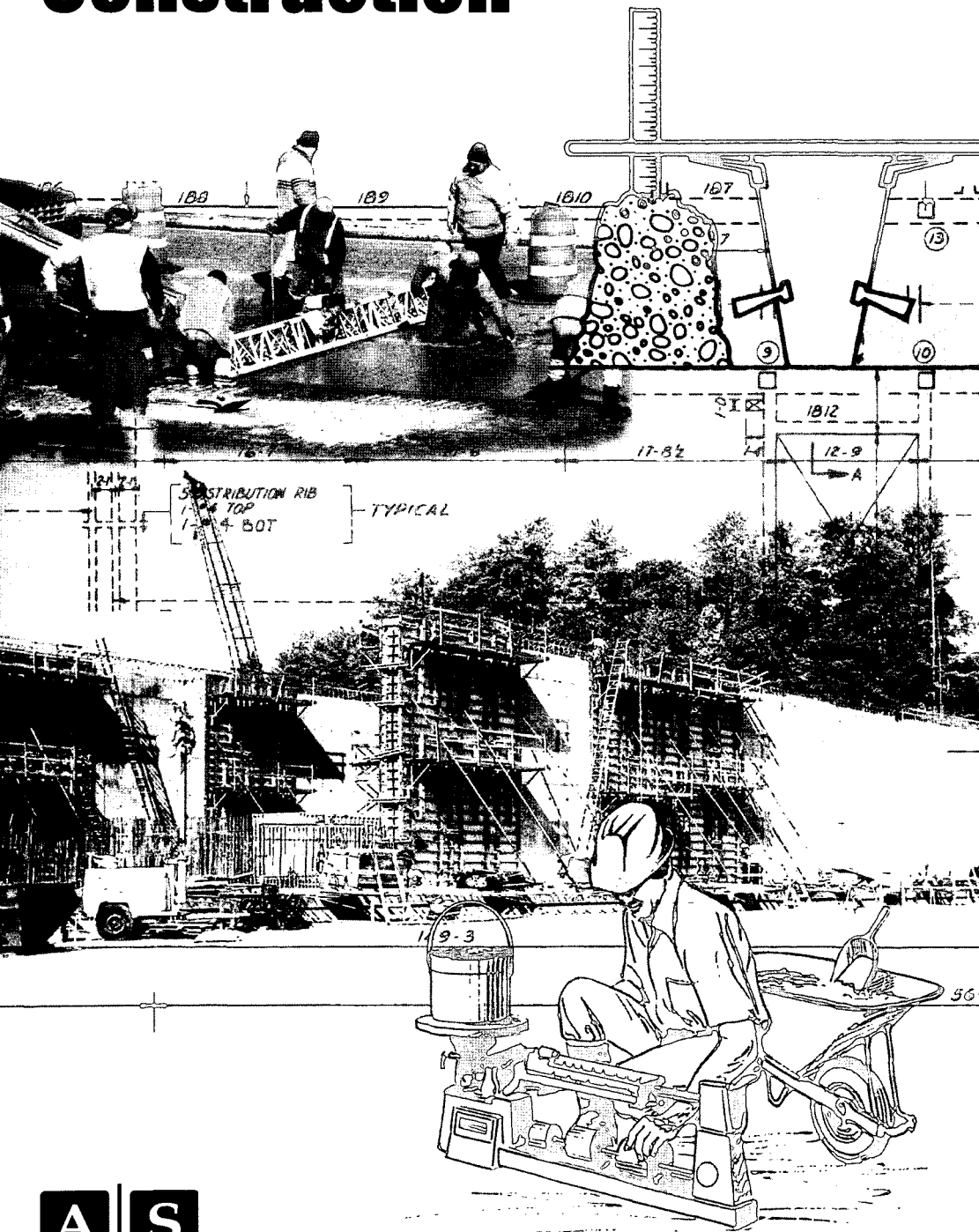


The Contractor's Guide to Quality Concrete Construction

Third
Edition



AMERICAN SOCIETY OF
CONCRETE CONTRACTORS



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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).

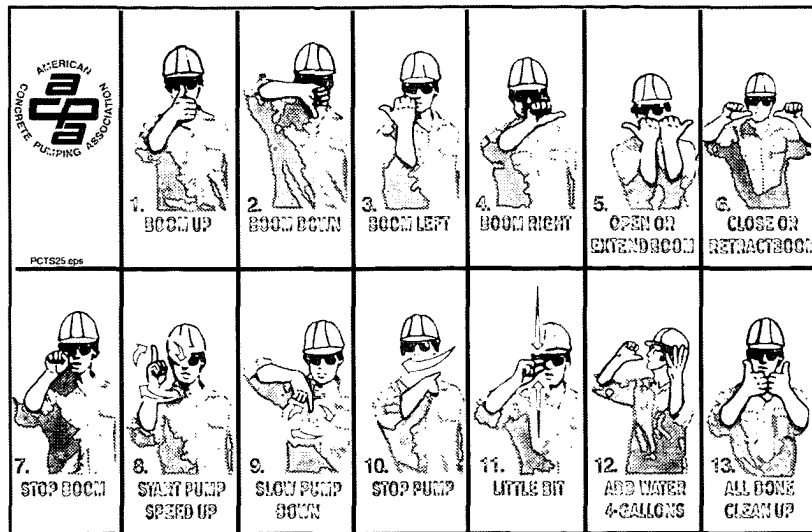
Every concrete project is unique. Casting a slab on ground is quite different from casting the 40th floor of a high-rise office building. Each has dangers that can be avoided, if we are aware of those dangers. That is why, in addition to the *ASCC Safety Manual*, every contracting firm must develop a 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.

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



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Chapter 1:

Organizing for Quality

The American Society of Concrete Contractors and the American Concrete Institute are dedicated to continually improving the quality of concrete construction through experience, sharing, and education.

Quality concrete construction is achievable when all levels of management insist on quality and all employees know what is expected of them. It is always less costly to build it right the first time.

How does the employee know that quality is a basic company requirement? When he is trained in what is expected of him and when he sees poor workmanship or materials removed and replaced voluntarily by the company regardless of the cost.

Consistent quality construction can only occur when each person knows that he/she has been properly trained and is expected to produce quality work. Quality construction then becomes the norm rather than the exception.

Quality Control

Although everyone should be aware of their quality responsibilities, there must be a system of quality control, including inspections.

Inspection does not take responsibility away from the construction worker. It provides management with a measure of the level of quality and the data for improving the system.

Every contractor, no matter the size of the company, should feel personally responsible for quality and must instill the feeling in each employee that, "We do quality construction and are proud of each of our projects."

One of the first tasks of management for any size company is to develop a written plan for quality control including which parts of each phase of a project are critical to quality, when they should be checked, and by whom. A checklist can then be developed for inspection

by the quality control personnel or, in a small firm, the knowledgeable person who will do the inspection.

The number of people devoted to quality control will vary with the size of the job and its complexity. People must be available to verify that materials arriving at the jobsite meet project specifications.

Qualified personnel must be available to complete required inspections on time with minimum delay of work crews.

Ideally, every jobsite should have at least one American Concrete Institute (ACI) Grade I Certified Technician available.* ACI certification programs are designed to provide the basis for training and certifying experienced personnel, alleviate problems related to improper job practices, upgrade the quality of concrete construction, and prepare the industry for possible future mandatory certification requirements. Several technician, inspector, and craftsman programs are available for sponsorship by local, state, and national organizations.

For the small concrete contractor, only one or two qualified persons may be required to handle quality control. As a company grows, or when several jobs are underway, more people can be added until an organized quality control department is in place.

Even with one quality control person, there should be a clear sense of organization. The quality control people should report to company management, not to jobsite management. The reason? The person responsible for jobsite schedules often faces conflicts between the goals of quality construction and meeting a tight completion schedule.

Quality control should not be dependent on schedule, and a schedule should not be delayed by a lack of quality

*Contact ACI at (248) 848-3700 for information on Certification classes to be held in your area.



control personnel. The quality control effort, however, works best when it is in tune with the construction team's schedule demands.

To build this harmony, management needs to participate in meetings of the quality control personnel, the foremen, and their crews on quality shortcomings. The purpose of quality control meetings should be to pinpoint inadequate procedures and equipment, and to improve the knowledge and skills of the people doing the work.

Management should use these meetings to strengthen the purpose of the quality control program—that is, to improve quality, not to pin the blame for lapses in quality on a particular person or department.

Improved quality means more business for the company, lower costs (it is less costly to build it right the first time), and continued employment for construction workers and quality control personnel.

Record Keeping

A good quality control program will include organizing a complete and accurate record of operations. A recorded diary of a construction project is extremely valuable, especially when a problem develops. Daily photographs, properly dated, can also be beneficial.

In general, records of the following construction operations should be included in the quality control system:

- Identification, examination, acceptance, and testing of materials and subassemblies.
- Inspection prior to casting concrete, including a check of form dimensions, size and position of reinforcing or prestressing steel, joint materials, inserts, form condition, cleanliness of reinforcement, shoring and support for forms, and the condition of soil in excavations.
- Preparation of concrete specimens and their proper storage while awaiting testing. Performance of tests for slump, compressive or flexural strength, air content, and density (unit weight).
- A quality project will require the care and coordination of embedded materials (weld plates, piping, conduit, floor drains, sleeves, openings) in both horizontal and vertical concrete work.
- The quality of a concrete project can be greatly improved through the use of concrete coordination drawings (lift drawings or shop drawings) to assist in the location, routing, temporary support, sealing, construction joints, anchor bolts, reinforcing steel, weld plates, piping, conduit, grounding, floor drains, plumbing, sleeves, openings, and blockouts. It is extremely important to assure that architectural concrete surfaces and floor tolerances (F-numbers)

be apparent on the drawings.

- Inspection of form removal, and finishing of formed and unformed surfaces. (Quality control personnel should know that it is good practice to remove interior forms first. This relieves pressure on the outside corners, reducing the chance of cracking the corners during form removal.)
- General observation of equipment, working conditions, weather, and other items that could affect the long-term durability of the concrete. Curing and protection from the elements should also be observed. Temperature records are particularly important.
- Records should be kept on materials testing; concrete proportions; placing, finishing, and curing of concrete; size, placement, and cover over steel reinforcement; details on welding that may affect quality; plus details on subgrade preparation for slabs on ground and foundation footings. A checklist can provide a record of such inspections.
- The owner's representative, after witnessing or making an inspection required by the specifications, should sign the inspection report, including a statement describing what was inspected, when, and what action is required. This should become a part of the job records.
- Prepare and periodically update a pre-construction checklist (refer to Chapter 9 for an example).

Contract Documents

The purpose of a concrete construction quality control organization is to ensure that the project is being constructed in compliance with plans and specifications (the contract documents).

Contract documents are a part of a legal, binding contract and must be treated with high regard. The purpose of contract documents is to ensure that the quality of workmanship, tolerance control, or materials needed for the finished construction are as specified, and will produce construction that will perform as intended by the designer.

Sometimes contract documents may conflict with local practice or the experience of the contractor. Should a contractor find that the quality of the project as specified cannot be achieved, he should seek a meeting with the designer to fully discuss the issue. All such meetings, and the decisions reached, should be recorded and kept with the contract documents.

Quality and Profit

Every concrete contractor faces two choices regarding quality. He can pay the controlled cost of a quality control system designed to provide the appropriate level of quality, or the uncontrolled costs associated with low-quality work.



Documents

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The direct and indirect costs of low quality can be high for repairing or patching unacceptable work, removal and/or replacement of portions of the work, unmet schedules, and the high costs of litigation.

Poor quality means customer dissatisfaction. The customer worries as much about problems not detected as those that are detected. A dissatisfied customer seldom creates new work for a contractor, which becomes a hidden cost of poor quality.

Contractors should aim for an appropriate level of quality that fully meets the requirements of the customer's project. Extremely high, unrealistic levels of quality that go far beyond the requirements of the project can be very costly without providing any increase in customer satisfaction.

The contractor who carefully tests incoming materials and verifies the proper placement of reinforcing steel, form tolerances, concrete strength, and other specifiable portions of the construction will have quality and costs under control. The firm will have few if any costly surprises.

A quality project will require the care and coordination of embedded materials (such as weld plates, piping, conduit, floor drains, sleeves, and openings) in both horizontal and vertical concrete work.

A quality-controlled job has the lowest cost to the contractor and the greatest satisfaction for the specifier and owner. Customer satisfaction means repeat, or referral, business.

The most profitable way to build is to do it right the first time. It saves the contractor money and time, and it saves the client the extra costs that occur when a project cannot be occupied on the scheduled date.

Ideally, a contractor should have both a cost-control system and a quality control program. Careful review of both provides the information needed to determine optimum quality and cost.

The Construction Team

Reinforced concrete construction involves several professions and trades: owner's representative, architect, structural engineer, general contractor/construction manager, concrete specialty contractor, reinforcing steel placing specialty contractor, ready-mixed concrete supplier, reinforcing steel fabricator, detailer, on-site worker, and inspector.

The architect prepares drawings that determine the general design of buildings and writes the general specifications. For bridges and heavy construction projects, these functions are usually performed by the engineer.

The structural engineer prepares the structural design

for buildings, shells, and other complex structures. This includes determining the type of building frame, computing the design of structural members, determining the size, shape, and location of reinforcing bars, preparing specifications and engineering drawings, and reviewing shop drawings.

The general contractor/construction manager is responsible for construction of the project and supervises the work of the specialty contractors, which includes the concrete and reinforcing steel placing specialty contractors. Pre-planning is essential to the success of the project. The NRMCA/ASCC Checklist for the Concrete Preconstruction Conference can be found in Chapter 10.

The concrete specialty contractor is responsible for the concrete portion of the contract documents.

The reinforcing steel placing specialty contractor positions the reinforcing bars prior to the placement of concrete.

The ready-mixed concrete supplier batches and delivers concrete to the jobsite.

The reinforcing steel fabricator fabricates the reinforcing steel and delivers it to the jobsite. This service generally includes the preparation of placing drawings. Sometimes the fabricator is also the placing subcontractor for the reinforcing steel. The contractor (not the rebar fabricator) should control when and how the reinforcing steel is delivered to the construction site.

The detailer prepares placing drawings and bar lists from engineering drawings.

The on-site workers include the carpenter, ironworker, cement mason, and laborer.

The inspector can be of three types—one representing the owner, one employed by the contractor, and one employed by the local building department whose job is to enforce the building codes. The inspector examines work in progress to see that it conforms to project drawings and specifications. The owner's inspection forces will often place emphasis on inspection of concrete materials, testing of plastic and hardened concrete, verification of substrate quality and compaction, and inspection of the finished structure. The contractor's quality control inspection will emphasize examination

of setting of formwork, concreting processes, substrate bearing capacity, and placement of reinforcement.

Good reinforced concrete construction depends on the skill of this entire team. Success of the project hinges on the accuracy and fidelity with which the contractor and his staff carry out the often complex instructions of the designer and the detailer. Experienced crews are a key to the productivity needed to bring a contract in on schedule. Additional time saving is possible when the job is thought through in advance by an experienced detailer who understands field placing problems with input from those responsible for placing concrete and steel.

Recommended Reading

ACI Committee 121, "Quality Assurance Systems for Concrete Construction (ACI 121R-85)," American Concrete Institute, Farmington Hills, Mich., 1985, 7 pp.

Bimel, Carl, "Organizing for Quality in Construction," *Concrete International*, V. 17, No. 11, Nov. 1995, pp. 54-55.

Crosby, Phillip B., *Quality is Free*, Mentor Books, Modern Executive Library, New York, 1980.

Hays, C. Raymond, "Achieving Quality in Concrete Construction," *Concrete International*, V. 17, No. 11, Nov. 1995, pp. 52-53.

Quality in Concrete Construction, C-38, American Concrete Institute, Farmington Hills, Mich., 1997, 60 pp.

Chapter 2:

The Concrete Mix

A concrete mix that complies with the specification is only the start. It should be the most economical mix that will meet the project requirements for strength and durability. At the same time, it must meet the contractor's requirements for placing and finishing.

The ready-mixed concrete producer or testing laboratory will usually be responsible for the actual mix proportions. But the contractor's knowledge of concrete materials and the principles of mixture proportioning, combined with a close working relationship with the ready-mix producer, will enhance the quality of the job, decrease the construction costs, and add to the profit for both.

Depending on whether the concrete is to be deposited directly on the subgrade or in forms, chuted over a distance, buggied, pumped, conveyed, or placed by bucket, in hot or cold weather, adjustments almost always have to be made to the mix. These changes can affect economy, speed of construction, ease of placement and finishing, and quality, and they can meet special requirements such as high early strength for post-tensioning or early form removal.

Control Tests

The characteristics of the concrete mix that are most important to the contractor, both for meeting needs on the job and for complying with the specification, are defined by four common field tests.

Control tests for slump, air content, compressive strength, and yield should conform to the appropriate ASTM specifications. Sampling fresh concrete is governed by ASTM C 172.

All field control tests and the taking of field samples should be performed by an ACI Concrete Field Testing

Technician, Grade I or above, or equivalent.

If the concrete contractor employs an ACI Certified Concrete Field Testing Technician, Grade I, it would be wise to cast companion cylinders made from the same load of concrete sampled by the testing laboratory or the general contractor. This may be necessary to verify the adequacy of the testing procedures. Inspection and specification enforcement is not a one-way street—inspecting the inspection procedures often improves the quality of testing.

Sampling (ASTM C 172)

Prior to starting the job, establish where test cylinders will be made and stored and at what point in the transport of the concrete testing samples will be taken. The contractor needs to know that the concrete will have the needed slump and workability at the point of placement. For example, when using a water-reducing admixture, the concrete could have a slump of 2 to 4 in. before the admixture is added and up to 8 in. at the point of delivery after the admixture is added.

Slump (ASTM C 143)

The slump test is used to measure the consistency of the concrete. The slump gives an indication of the workability, plasticity, or flowability of the concrete. It is especially useful as an indicator of the fresh concrete's uniformity from one batch to another as delivered to the job.

Variations in slump are caused by changes in water content, air content, admixtures, aggregate proportions and gradation, delivery time, and temperature. The slump test should be performed in accordance with ASTM C 143, "Standard Test Method for Slump of Hydraulic Cement Concrete." Figure 2.1 shows the setup, and Fig. 2.2 shows the sequence of steps for performing a slump test.



Air Content (ASTM C 231 and C 173)

Air-entrained concrete contains many microscopic, evenly spaced air bubbles introduced by the addition of an air-entrainment admixture. The most important benefit of air entrainment is that it improves the concrete's resistance to damage from freezing and thawing cycles and from the application of deicing chemicals. The microscopic entrained air voids provide a source of internal pressure relief within the concrete to accommodate the pressures that develop as ice crystals form in the pores and capillaries of the concrete. Without the proper air content, normal concrete that is exposed to freezing and thawing cycles will scale and

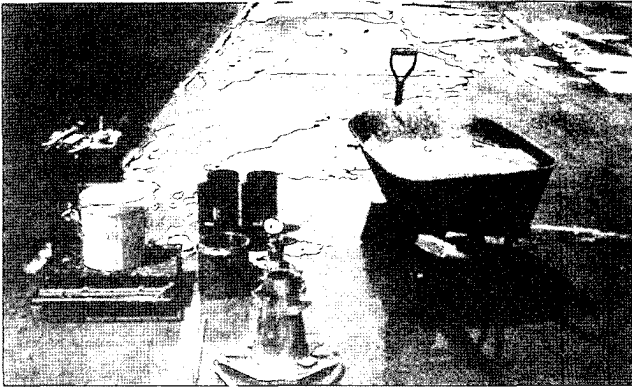


Fig. 2.1 — The technician has the equipment in order before starting the tests. Note that the equipment includes a scale for determination of density and yield.

spall, resulting in a durability failure of the concrete. Under these conditions, even the best construction practices will not produce durable concrete without air entrainment.

Variations in air content affect not only durability, but placeability, finishing qualities, and yield. Many conditions affect the amount of entrained air in concrete, such as: characteristics of aggregates, nature and proportions of constituents of the concrete admixtures, type and duration of mixing, consistency, temperature, cement fineness and chemistry, and use of other cementitious materials or chemical admixtures (ACI 211.1-91 Section 4.2).

Frequent testing is necessary for maintaining air contents at the required level. The two primary methods for measuring air content in fresh concrete (Fig. 2.3) are ASTM C 231, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method," and ASTM C 173, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method." The air indicator, shown in the far right photo of Fig. 2.3, is not as accurate as the two other methods and should not be used for acceptance or rejection of concrete.

Compressive Strength Tests (ASTM C 31 and C 39)

The compressive strength of concrete is measured by testing concrete cylinders (usually 6 in. in diameter and 12 in. high) in the laboratory. Cylinders are tested

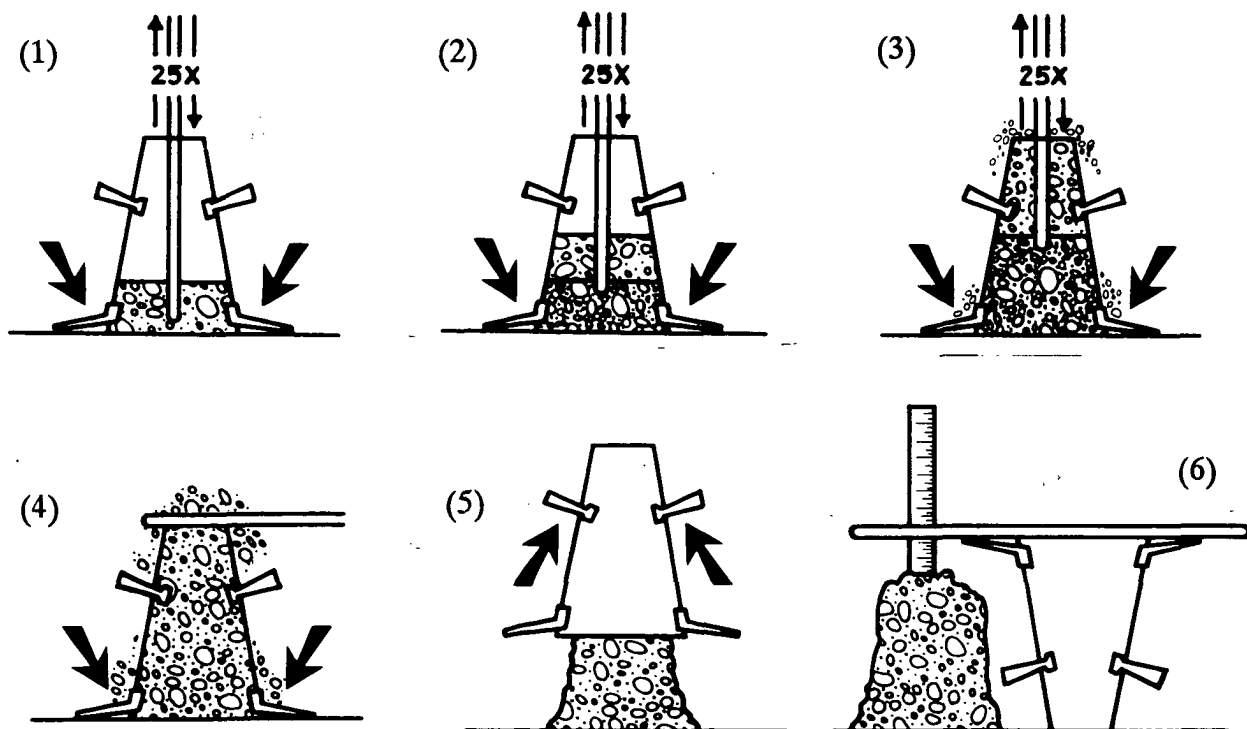


Fig. 2.2 — Measuring the slump of fresh concrete. The cone is filled with concrete in three layers of equal volume (Steps 1, 2, and 3). Each layer is rodded 25 times with a steel tamping rod. After the top surface is smoothed (Step 4), the slump cone is slowly lifted vertically (Step 5) and turned upside down. The slump is measured (Step 6) as the distance that the center of the top surface has settled. (Drawing courtesy of Master Builders, Inc.)

for two purposes: for acceptance testing (to determine whether or not the concrete as delivered to the job meets the specified strength) and to estimate the strength of the concrete at a given time.

ASTM C 31, "Standard Practice for Making and Curing Concrete Test Specimens in the Field," governs the making of test cylinders (Fig. 2.4 and 2.5). For

acceptance testing, two cylinders are made from the same concrete sample and tested at 28 days (unless otherwise specified). **The average of the strengths of the two cylinders constitutes one test, which is used as part of the strength evaluation for acceptance of the concrete.**

A third cylinder, made at the same time, is tested at

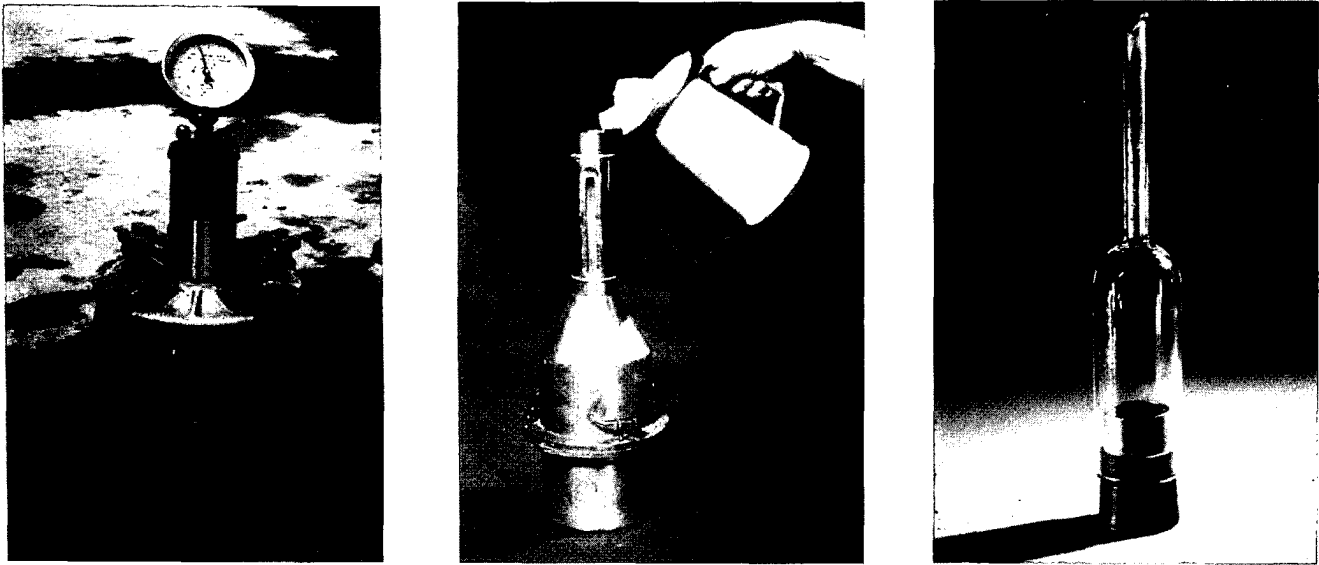


Fig. 2.3 — **(Left)** A pressure air meter is used for normalweight and heavyweight concrete. The air content is determined by compressing the sample under a controlled air pressure and reading the air content on the dial. **(Center)** A volumetric air meter is used for lightweight as well as normal and heavyweight concrete. The meter, containing a measured sample and filled with water, is rolled to remove the air. The air content is read off the gauge on the stem. **(Right)** An air indicator. The air content is estimated from a very small sample in the base. The air is removed from the sample by filling the vial with isopropyl alcohol. The air indicator is not considered to be as accurate as the pressure or volumetric air meter and should not be used as a basis for acceptance or rejection of concrete. (This is not an ASTM test method.)



Fig. 2.4 — Concrete test cylinder molds are filled with fresh concrete in three equal layers, each layer being rodded 25 times. Each cylinder should be labeled and capped or otherwise protected to prevent loss of moisture.

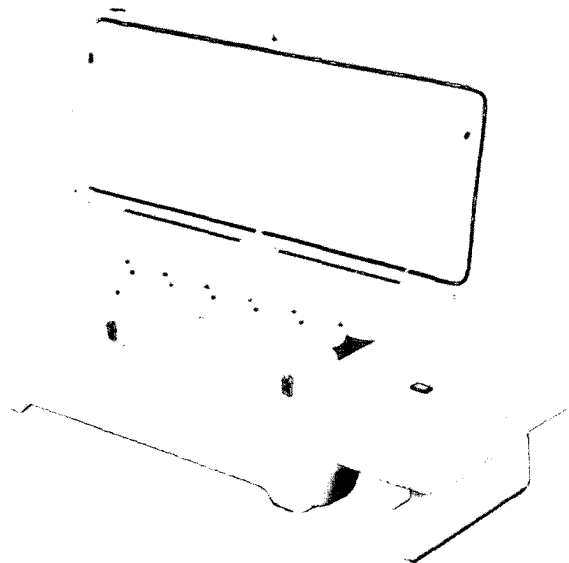


Fig. 2.5 — Cylinders must be kept at a controlled temperature while stored on the job. Cylinders stored in this curing box are protected against hot summer sun or cold weather. A controller constantly monitors and maintains a constant temperature, displayed on an LED. Lack of protection or improper handling can drastically reduce cylinder strength.

7 days. The 7-day test is informational only and is not a part of any strength evaluation. It is anticipated that the 7-day strength will be approximately 65 to 70 percent of the 28-day test.

When used for acceptance, cylinders must be protected at a controlled moisture and temperature while stored on the job. Within 48 hours of making, the cylinders must be transported to the laboratory under controlled conditions and stored at a controlled moisture and temperature until tested.

Every contractor should recognize that ASTM C 31 is a commonly violated standard, resulting in low, invalid test results. Test results from nonstandard testing should not be used as a basis for acceptance or rejection of concrete. The technician performing the strength test should be certified as an ACI Concrete Laboratory Testing Technician, Grade I or II, or by an equivalent written and performance test program.

In-place strength estimates for concrete ages other than 7 or 28 days are often necessary to facilitate post-tensioning, opening of the work to traffic or service, removal of shoring and bracing, or removal of forms. In many cases, accurate in-place strength data can save the contractor time and money in the performance of these functions.

One method is to test cylinders that have been stored on the job site under conditions as similar as possible to the conditions of the concrete in place. These tests are informational only and are not a basis for acceptance or rejection of concrete.

Another way to estimate in-place strength is the maturity method. This method is growing in popularity because results are obtained in "real time," and the procedure is nondestructive. No cores need be drilled and no holes need be patched. Thermocouples, which essentially are wires that transmit temperature to a sensing device, are used in the laboratory to establish a strength versus maturity relationship for the mix that will be used on the project. The concrete's maturity is essentially the concrete temperature multiplied by the time the concrete is maintained at that temperature. When the concrete is placed on the job, thermocouples are cast into the concrete and extended outside the forms. Some sort of data logger is connected to the thermocouple to continuously monitor temperature over time so that maturity can be determined at any time following concrete placement. This value can then be plotted on the established strength gain versus maturity curve to provide the contractor with reliable in-place strength data.

Compressive strength tests may also be used to estimate flexural strength once a relationship between compressive strength and flexural strength

has been established. Refer to the section entitled "Flexural Strength" in Chapter 3 for a more complete description.

Density (Unit Weight) and Yield (ASTM C 138)

Yield is the volume of freshly mixed concrete produced from a known quantity of ingredients; it is the total weight of ingredients divided by the unit weight (or mass) of the freshly mixed concrete. The yield of a concrete batch is computed to confirm the volume of the concrete mix—that a cubic yard of concrete as batched according to the mix design actually produces a cubic yard of concrete when delivered to the job. ASTM C 138 uses the unit weight method for determining yield.

A lower mass (unit weight) from that established by the mix design may indicate:

1. that the materials have changed (lower specific gravity),
2. a higher air content,
3. a higher water content,
4. a change in proportions of ingredients, or
5. lower cement content.

Before any questions about yield arise, the contractor and ready-mixed concrete producer should check the density in the field. The test requires weighing a known volume of concrete ($1/4$ to 1 ft^3) from a load and comparing it to the actual batch weight (Fig. 2.6).

The testing laboratory should weigh and record with each strength test the weight of each cylinder. This is a useful check for uniformity and yield.

Cement

Project Specifications for Cement

Almost all project specifications include a specification for portland cement, requiring compliance with

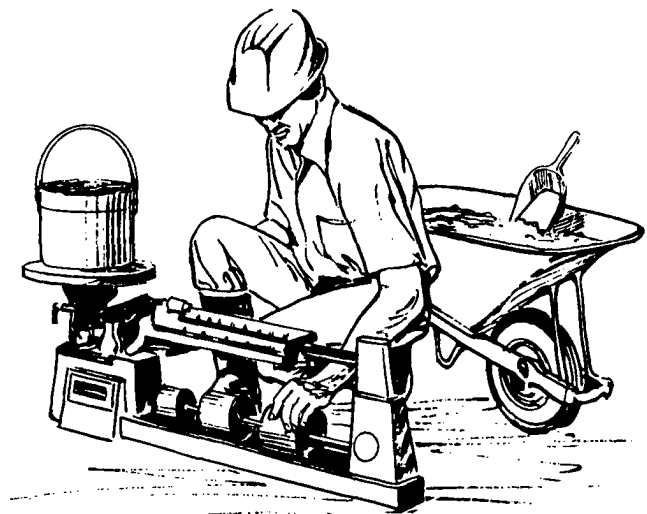


Fig. 2.6 — To determine the unit weight of concrete, weigh a level-full container of concrete, subtract the weight of the empty container, and divide by the volume of the container.

ASTM C 150, “Standard Specification for Portland Cement,” or ASTM C 1157, “Standard Specification for Hydraulic Cements.”

Many project specifications also include a specification for blended cements, requiring compliance with ASTM C 595, “Standard Specification for Blended Hydraulic Cements.” The blended cements are most commonly a blend of portland cement and a pozzolan (usually fly ash) designated Type IP, or a blend of portland cement and finely ground granulated blast furnace slag designated Type IS. To ensure a uniform blend, the fly ash or slag is sometimes interground with the portland cement.

Portland Cement Manufacture

The basic ingredients in portland cement are limestone and clay or shale. From these raw materials come the elements—calcium, silica, iron, and alumina—that make up the chemical compounds in cement.

The raw materials are proportioned to control the chemical composition and burned to form a clinker of pellet-sized particles. After cooling, the clinker is ground with the addition of a small percentage of gypsum; the end product is portland cement. When combined with water, the chemical reaction of hydration takes place and the cement paste (cement plus water) hardens. The gypsum acts as a regulator for the setting time.

Basic Types of Portland Cement

There are five basic types of portland cement, designated by type:

Type I is a general-purpose cement that is used in the vast majority of concrete.

Type II is generally used where reduced heat of hydration is needed (large footings or foundations, for example) or where moderate sulfate resistance is desired. Type II cement usually has a lower early strength than Type I. Cement designated Type I/II meets both Type I and Type II specifications and may be used where either is specified.

Type III is a high-early-strength cement. As a rough comparison, a Type III cement achieves about the same strength at 1 day as a Type I does in 3 days; also, a Type III cement reaches the same strength in 7 days that a Type I reaches in 28 days. Beyond two or three months, there is little difference in long-term strengths.

Type IV is a low heat-of-hydration cement, limited in use to massive structures such as dams. In Types I, II, and III, heat buildup from hydration can cause severe thermal distress within the concrete. Type IV has a lower early strength than Types I, II, III, or V.

Type V is a sulfate-resistant cement, limited to use where high sulfate soils, solutions, or groundwater are

found. Type V may have a lower early strength than Types I, II, or III.

Types IV and V may be limited in availability. Whenever these cements are specified, the contractor should confirm their availability, additional costs that might be involved, and possible alternatives such as blended cements that may be acceptable either because of availability problems or for economy.

Air-entraining cements contain an interground air-entraining agent; some manufacturers produce Types IA, IIA, and IIIA cements. The need for air-entraining cements has been largely replaced by the use of air-entraining admixtures, and they are not as widely produced as they once were.

Other Cementitious Materials

Several other materials may be combined with portland cement to make up the total cementitious content of the concrete mix.

Fly Ash

Fly ash is a byproduct of coal-burning power plants and is classified as a pozzolan. The particles of fly ash are spherical in shape, generally finer than cement. Fly ash in bulk is very similar to cement in its appearance and its physical and chemical properties.

When used with cement in a concrete mix, fly ash reacts with calcium hydroxide, a chemical byproduct of cement hydration, producing the same binder as portland cement. Through this “pozzolanic” reaction, fly ash becomes a part of the total cementitious material.

When fly ash is used in concrete, it is usually to replace part of the portland cement content. Because reactions vary, the mix must be proportioned specifically for the cement and fly ash being used.

Two classes of fly ash, Class C and Class F, are generally used in concrete. Class F fly ashes are usually associated with lower early strengths, but with additional later strength gain and greater chemical resistance. Class C fly ashes will more nearly match the rate of strength gain of a straight portland cement mix. The lower early strengths associated with Class F fly-ash concrete can be a disadvantage for some applications—for example, in cold weather or on a post-tensioning job where low early strengths would delay stripping of the forms or tensioning of tendons.

Fly ash concrete can be more economical than non-fly-ash concrete if the fly ash is readily available.

The particle shape of fly ash enhances workability, especially in mixes with low cement content; it is also an aid in pumping concrete. Most Class F fly ashes make concrete more resistant to sulfates and alkali-silica reactions. Fly ash usually reduces the air content in air-

entrained concrete, so a larger amount of air-entraining agent is needed to maintain the required amount of air.

Microsilica (Silica Fume)

Also classified as a pozzolan, microsilica is a byproduct of the manufacture of silicon metals. Microsilica particles are approximately 1/100 the size of cement particles. Because of its extreme fineness, practical methods for adding microsilica to a concrete mix are in a slurry or a compacted form.

The primary benefit of microsilica is increased durability. It provides increased corrosion protection for the reinforcement by making the concrete less permeable, resulting in greater resistance to penetration of aggressive agents such as chlorides.

A major application for microsilica is in high-strength concrete, where compressive strengths of 14,000 psi or greater are possible.

Granulated Slag

Finely ground granulated slag [also called ground granulated blast furnace slag (GGBFS) or slag cement] is used as a partial replacement for cement. While not classified as a pozzolan, it has both pozzolanic and cementitious qualities and can improve sulfate resistance, reduce permeability, and increase long-term strength. It can also be used to create a lighter-colored concrete.

Mixing Water

The quality of the water in the concrete mix is rarely a problem. As a general rule, water fit to drink is suitable, so water from any municipal supply should be acceptable. Distinct taste or odor would be a warning, however, that tests should be made.

Criteria for tests for questionable water are contained in ASTM C 94, "Standard Specification for Ready-Mixed Concrete." The primary tests are 7-day compressive strength of mortar cubes and time of set.

Control of the amount of mix water is of primary concern in ensuring the quality of concrete desired. Water serves two purposes: to combine chemically with the cement, and to provide needed workability. The chemical reaction of water with the cement is called *hydration*. During the reaction, the cement paste gives off heat—the *heat of hydration*—as it binds with the aggregate. In a normal range of mixes, the water required for hydration is no more than about half the total amount of water required for workability. In terms of hydrating the cement, about half the water in the mix is excess water. The highest quality concrete will be attained when the excess water required for workability is held to a minimum.

Water-Cementitious Material Ratio*

Cement and water make up the cement paste that bonds the aggregates together in the hardened concrete. The stronger and less porous the cement paste is, the stronger and more durable the concrete will be. Any water not needed for workability simply dilutes the cement paste, weakening it and making it porous. With that principle in mind, the water-cementitious material ratio (abbreviated w/c or $w/(c+m)$) is used as a basis for concrete mixture proportioning.

Since concrete is usually batched by weight, the w/c is usually computed in pounds of water per pound of cementitious material. If the mix contains 300 lb of water, 464 lb of cement, and 100 lb of fly ash, the w/c would be

$$300 / (464 + 100) = 0.53$$

Remember, a higher w/c lowers the strength and adversely affects other qualities of concrete as well.

Aggregates

The aggregates are most important to the mix as an inert filler material. They are not a part of the chemical reactions that cause the cement paste to harden. They affect the quality of the concrete through the soundness of the aggregate particles and their gradation.

Certain exposure conditions such as severe abrasion or sustained high temperatures may require select aggregates. The vast majority of conditions, however, will be met with standard materials and good construction procedures. Concrete with well-graded, properly proportioned aggregates will require less cement paste for coating the aggregate particles and will be more economical than a poorly graded mix (Fig. 2.7).

The 1/4-in. sieve is the dividing point between coarse and fine aggregates (Fig. 2.8). Fine aggregate passes the 1/4-in. sieve, and coarse aggregate is retained on it. ASTM C 33, "Standard Specification for Concrete Aggregates," contains gradation specifications for both fine and coarse aggregates. ASTM C 33 also limits materials that may prove to be harmful to concrete, such as organic materials and soft or highly porous particles.

* The *water-cementitious material ratio* is the more correct term for what used to be called simply the water-cement ratio, so called because portland cement was the only ingredient in the concrete mixture that chemically reacted with water to become the cementing agent. With the advent of pozzolans such as fly ash and microsilica becoming part of the cementitious materials, the term is more correctly referred to as the water-cementitious material ratio. In ACI literature, the water-cementitious material ratio is frequently abbreviated $w/(c+m)$ whenever another cementitious material or materials is/are employed with portland cement. Unless specially noted otherwise, this *Contractor's Guide* uses the abbreviations w/c and $w/(c+m)$ interchangeably to refer to the water-cementitious material ratio. Other common abbreviations are w/cm , $w/(c+p)$ (cement + pozzolans), or W/B (water-binder ratio).

KEEP AGGREGATE CLEAN

Although the aggregate is an inert filler in the concrete mixture, it must be sound to produce quality concrete. Some of the deleterious materials that are limited or prohibited by the aggregate specification are:

- **Clay lumps and easily crumbled particles:**
Unsound particles may affect durability and workability, cause popouts, and increase water demand of the mix.
- **Coal and lignite:**
Affect surface appearance, cause popouts, and cause difficulty in air entrainment.
- **Material finer than No. 200 sieve:**
Affects bond of paste to aggregate and increases the mix water demand.
- **Soft particles:**
Reduces durability and surface hardness.
- **Lightweight chert:**
Reduces durability and is a primary cause of popouts.

While the gradation from the largest to the smallest particles is important for both coarse and fine aggregates, the fine aggregate gradation has the greater effect on the important qualities of the concrete for placing and finishing. Oversanded mixes or mixes with very fine sands require more water and may prove to be sticky and hard to finish. Undersanded mixes or mixes with coarse sands may allow excessive bleeding or may cause harsh finishing. This is more likely to occur with manufactured sand than with natural sand. Air entrainment is helpful in overcoming the harshness of a mix and compensates in part for sands lacking in very fine material.

An ideal gradation would occupy a numerical position somewhere in the center of the specification limits.

Some areas of the country do not have a local source of well-graded coarse and fine aggregates. Many contractors have compensated by substituting fine sands for 1/4- or 3/8-in. stone or for coarse sand. **This is an extremely poor practice!** Well-graded aggregates will solve many problems related to the concrete mix.

The maximum size coarse aggregate is often specified for meeting specific job conditions. As a general rule, the maximum size aggregate is limited to the lesser of one-quarter the space between side forms, three-quarters the space between reinforcing bars, or one-third the depth of a slab on ground. Maximum aggregate sizes are usually 3/8, 3/4, 1, or 1-1/2 in. As a general rule, a mix using the largest allowable size aggregate will be the most economical, although a maximum of 3/4 in. or less is recommended for high-strength concrete.

Because of the difference in particle shape, crushed stone mixes usually require a higher sand content and slightly more water for workability than mixes made with rounded gravel aggregates.

In the absence of well-graded coarse and/or fine aggregates, use of an intermediate aggregate should be considered to improve combined aggregate gradation.



Fig. 2.7 — A polished cross section of concrete shows the aggregate, as the filler in the mixture, bonded together by the cement paste.

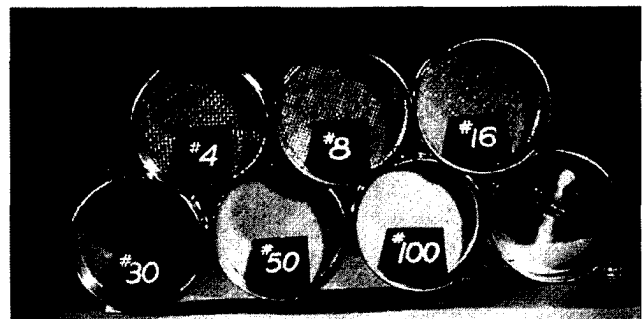


Fig. 2.8 — The gradation of both coarse and fine aggregates is measured with standard sieves. To determine the gradation of a sand sample, the sieves would be stacked with the #4 sieve (4 openings per inch) on top. When the sieves are shaken, the sand particles are separated out according to size.

Many concrete suppliers stock aggregate with a nominal maximum size of 3/8 in., and use of an appropriate quantity of this or another intermediate aggregate will improve the combined aggregate gradation.

To determine if aggregates are well graded, it is



Fig. 2.9 — A batch plant control room where the operator can monitor the batch weights of materials, including admixtures. (Photo courtesy of Automated Control Technologies, Inc., and Stephens Manufacturing Co.)

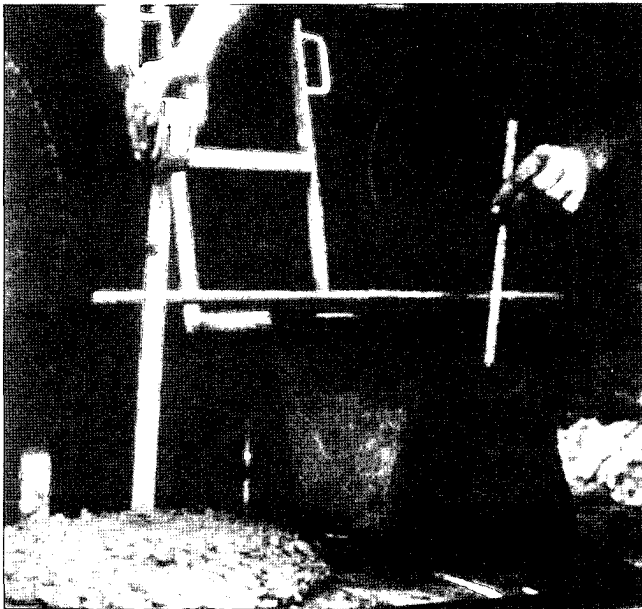


Fig. 2.10 — This photograph illustrates the difference in slump before and after adding superplasticizer.

necessary to know the combined aggregate gradation. To accomplish this, the concrete mix design should show, for each aggregate, typical percentages passing the following sieves: 2, 1-1/2, 1, 3/4, 1/2, and 3/8 in.; #4, #8, #16, #30, #50, #100, and #200; and the bulk specific gravity (SSD) of each aggregate.

Admixtures

Admixtures, when properly used, can increase early strength, increase ultimate strength, accelerate or retard setting time, increase workability, improve uniformity, reduce permeability, and improve durability. The specifications governing chemical admixtures, chemical admixtures used to produce flowing concrete, and air-

entraining agents are ASTM C 494, ASTM C 1017, and ASTM C 260, respectively. These admixtures are usually added at the batch plant (Fig. 2.9). They are dispensed into the batch in measured amount in a liquid form.

Water Reducers

Water-reducing admixtures enhance the workability of the concrete, making it possible to reduce the water by 5 percent or more. Since the strength is governed by the w/c , the cement content can be reduced the same percentage as the water while retaining the same workability and the same strength. *Mid-range water reducers* that offer a 5 to 18 percent water reduction provide for excellent workability, pumpability, and finishability.

Some water reducers have a tendency to increase the air content in air-entrained concrete; therefore, the air-entraining agent must be adjusted accordingly (probably reduced by about a third). Some water reducers also often cause some minor retardation.

High-Range Water Reducers

Commonly known as superplasticizers, high-range water reducers may reduce the amount of water in the mix by over 30 percent (Fig. 2.10). They provide the convenience of high-slump concrete without the penalty of lower strength, long waiting time for finishing, or segregation that would occur if water were added to the mix. The increase in slump is only temporary; the mix then gradually loses slump. To get the benefit of a superplasticizer, the contractor must be ready at the time the increased slump is available. The addition of the superplasticizer typically turns a 2-in. slump into a 7- to 9-in. slump. Superplasticizers are available for jobsite addition or for addition at the batch plant.

Retarders

A retarder is usually used in hot weather to extend setting time, allowing more time for placement and finishing, and often causing a reduction in early strength. An overdose of a retarder, especially with fly-ash mixes, can cause extreme retardation (overnight or longer).

Accelerators

An accelerator is used to shorten setting time or to produce high early strengths. Its use is usually a cold-weather measure.

Calcium chloride is the least costly and most efficient accelerator. In recent years, however, serious questions have been raised about its contribution to corrosion of steel in reinforced concrete. Its use in nonreinforced concrete is not usually challenged. It is prohibited from use in prestressed concrete. The ACI Building Code (ACI

318) restricts its use based on the allowable chloride ion content in concrete.

Carefully examine any project specification before using any accelerator or water reducer containing chlorides. Nonchloride accelerators are readily available. They are more costly, however, and are probably less effective than calcium chloride. Also, they are likely to be less effective than Type III cement in producing high early strengths. Additional cement is another way to secure high early strength.

Water-Reducing Retarders

Retardation and water reduction are often combined in the same admixture.

Water-Reducing Accelerators

Acceleration and water reduction are often combined in the same admixture.

Air-Entraining Agents

In addition to being essential for durability when concrete is exposed to freezing and thawing and the application of deicing salts (Table 2.1), entrained air benefits concrete in other ways.

The microscopic air bubbles distributed throughout the cement paste make the concrete more workable, allowing a reduction in water content. The mix holds together better, is more uniform, and segregation is reduced. Entrained air reduces bleeding, makes harsh mixes easier to finish, improves pumpability, and contributes to impermeability of the hardened concrete.

Although entrained air is generally beneficial to concrete, too much air can weaken concrete and make it less durable. The specification writer should address performance requirements for permeability and shrinkage to ensure that the appropriate amount of air in the concrete is specified. Air-entrained normal-weight concrete must not be used for interior flatwork that is to be hard-troweled.

Other Admixtures

Various types of admixtures are available through manufacturers, such as shrinkage-reducing admixtures or chloride-inhibiting admixtures. Manufacturers should be consulted for recommendations.

Concrete Mix Design*

The most commonly used procedure for mixture proportioning referenced in most specifications is ACI 211.1, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete." The step-by-step procedure that is followed allows the mix to be proportioned to meet the requirements for any project.

Table 2.1 — Recommended Air Contents for Frost-Resistant Concrete

Maximum aggregate size (in.)	Average air content (percent)*	
	Severe exposure†	Moderate exposure‡
3/8	7-1/2	6
1/2	7	5-1/2
3/4	6	5
1-1/2	5-1/2	4-1/2
3	4-1/2	3-1/2
6	4	3

* A reasonable tolerance for air content in field construction is $\pm 1\text{-}1/2$ percent.

† Outdoor exposure in a cold climate where the concrete may be in almost continuous contact with moisture prior to freezing, or where deicing salts are used. Examples are pavements, bridge decks, sidewalks, and water tanks.

‡ Outdoor exposure in a cold climate where concrete will be only occasionally exposed to moisture prior to freezing, and where no deicing salts will be used. Examples are exterior walls, beams, girders, and slabs not in direct contact with soil.

Table 2.1 is adapted from ACI 201.2R, "Guide to Durable Concrete."

The mixture proportions will reflect requirements for:

- Compressive strength (based on w/c).
- Durability (including requirements for air entrainment, compressive strength, and cement type).
- Slump (based on minimum workability requirements for method of placement).
- Maximum aggregate size (limited by section dimensions and reinforcement spacing).

If shrinkage is a concern, a lower cement factor and larger aggregate should be used. The contractor should specifically discuss this with the architect/engineer.

The Right Mix for the Job

Take an example of a mix designed for a specific purpose—a floor slab for a commercial building, not subjected to heavy wear or to freezing and thawing. If the concrete is placed without vibration, ACI 211.1 recommends a maximum slump of 4 in. The maximum aggregate size is limited to one-third the depth of the slab. If the slab has a thickness of 5 in. or more, a 1-1/2 in. maximum size aggregate may be used.

Since freezing and thawing is not a problem, the w/c is based on the compressive strength† required for non-air-entrained concrete. For this example, suppose the specified strength is 4000 psi.

*Some prefer the term *mixture proportioning* to *mix design*. Both terms are used throughout this text.

† Project specifications may dictate performance requirements of the mix design, such as permeability and drying shrinkage, as well as compressive strength, which will influence the mix components.

Table 2.2 — Relationship between Water-Cement Ratio and Compressive Strength of Concrete

Compressive strength @ 28 days (psi)	Water-cement ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
6000	0.41	—
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

When the water-cement ratio required for strength differs from the maximum water-cement ratio for durability, the lower water-cement ratio is used.

Concrete exposed to freezing and thawing should always be air-entrained.

Strength is based on average strength of cylinders molded, cured, and tested according to ASTM C 31 and C 39 for checking the adequacy of the mix proportions. These cylinders are molded in the field, stored in the field under controlled moisture and temperature conditions, then moist cured in the laboratory until time of testing.

If Type II or V cement is used for sulfate or sea water exposure, water-cement ratio may be increased by 0.05.

Tables 2.2 and 2.3 are adapted from ACI 211.1.

The table from which the w/c is selected is based on average strength. With excellent control, the average strength required to meet a 4000 psi specification would be approximately 4500 psi. Poorer control (a wider range of strength test results) increases the average strength required (refer to the section “Items to Confirm in the Concrete Specification” in Chapter 3). From Table 2.2, the maximum w/c for a 4500 psi average strength would be 0.53.

From ACI 211.1, an estimate may be made of the mixing water needed per cubic yard for crushed stone or gravel aggregates and various slumps. For a 4-in. slump, using 1-1/2-in. crushed stone aggregate, that would be 300 lb. The cement content would then be $300 / 0.53 = 566 \text{ lb/yd}^3$.

The ACI standard provides for similar estimates to be made of the coarse and fine aggregate batch weights as well.

It is important to the contractor to know the variety of mixes that are available to do the same job, and to recognize the adjustments that can be made in a mix to improve placing and finishing conditions on the job.

Mix #1 in Table 2.4 is a typical example of a laboratory-proportioned mix using the ACI 211.1 procedure. The batch weights of the laboratory-proportioned mix will usually be determined for saturated surface-dry aggregates. That is important as a control measure. The aggregate has absorbed all of the moisture it can absorb, but no free moisture is on the surface of the aggregate particles.

In the field, where that saturated surface-dry condition doesn't exist, the free surface moisture in the aggregate becomes a part of the mix water. The batch weights of the aggregates must be increased, and the batch weight of the

Table 2.3 — Maximum Permissible Water-Cement Ratios for Concrete in Severe Exposures

Type of structure	Structure wet continuously or frequently exposed to freezing and thawing	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections less than 1 in. cover over steel	0.45	0.40
All other structures	0.50	0.45

water must be decreased by the same weight to compensate for the free moisture in the aggregates. (The opposite adjustment would be made in situations where the aggregates are so dry they absorb moisture from the mix.)

Free Moisture in the Aggregates (Table 2.5)

In Table 2.5, the effect of free moisture in aggregates on batch weights is illustrated for Mix #1 in Table 2.4. Batch A shows the batch weights if aggregates are in a saturated surface-dry (SSD) condition. Batch B shows batch weights if aggregates are relatively dry. Batch C shows batch weights for a normal or relatively common condition. Batch D shows batch weights if aggregates are relatively wet. It should be noted that the w/cm is the same for all batches, because they represent the same mix, regardless of the variation in batched water to compensate for variation in the free moisture in aggregates (free moisture in aggregates in Table 2.5).

The free moisture in aggregates, particularly sand, can vary significantly, and the use of incorrect moisture contents in the batching of loads is a prime reason for slump variation.

Water Reducer (Table 2.4, Mix #2)

When a water reducer is used a given slump can be obtained with less mix water depending on the type and dose of admixture or combination of admixtures used.

In Table 2.4, Mix #2 incorporates one water-reducing admixture (WRA) that reduces the water content by 8 percent. The table shows the effect on cement, aggregate, and water to produce a mix with similar absolute volume, w/c and slump to Mix #1. The 28-day cylinder strength of Mix #2 may exceed that of Mix #1, and the set time may be longer. If use of an accelerator is contemplated, consider the use of Mix #1 after verifying that it will

Table 2.4 — Example of Concrete Mixes (Non-Air-Entrained)

		Mix #1		Mix #2		Mix #3	
	Specific gravity	Absolute volume, * ft ³	Ingredients, lb/yd ³	Absolute volume, * ft ³	Ingredients, lb/yd ³	Absolute volume, * ft ³	Ingredients, lb/yd ³
Cement, lb	3.15	2.88	566	2.65	521	1.98	390
Fly ash, lb	2.40	0	0	0	0	1.00	150
Sand, SSD, lb	2.65	7.5	1240	8.12	1343	7.79	1288
Stone, SSD, lb	2.60	11.54	1872	11.54	1872	11.54	1872
Water, lb	1.00	4.81	300	4.42	276	4.42	276
Air (%)	—	0.27	—	0.27	—	0.27	—
Water-reducing admixture, [†] oz.	—	—	0	—	31.3	—	32.4
Mix weight, lb	—	—	3978	—	4012	—	3976
Density, lb/ft ³	—	—	147.3	—	148.6	—	147.3
w/cm	—	—	0.53	—	0.53	—	0.51

*27.00 ft³ = 1 yd³

[†]dose assumed to produce 8 percent water reduction.

Notes:

1. Entrapped air = 1 percent.

2. Adjust weights to correct yield based on measured density.

Table 2.5 — Example Concrete Mix #1 (Non-Air-Entrained), Effect of Free Moisture in Aggregates (FMA) on Batch Weight

	Specific gravity	Absolute volume, ft ³	Ingredients, Batch A, lb/yd ³	FMA Sand 0% Stone 0% (SSD)	Ingredients, Batch B, lb/yd ³	FMA Sand 0% Stone 0% (dry)	Ingredients, Batch C, lb/yd ³	FMA Sand 0% Stone 0% (normal)	Ingredients, Batch D, lb/yd ³	FMA Sand 0% Stone 0% (wet)
Cement, lb	3.15	2.88	566	—	566	—	566	—	566	—
Fly ash, lb	2.40	0	0	—	0	—	0	—	0	—
Sand, SSD, lb	2.65	7.5	1240	0	1278	38	1305	65	1333	93
Stone, SSD, lb	2.60	11.54	1872	0	1872	0	1872	0	1891	19
Water, lb	1.00	4.81	300	—	262	—	235	—	188	—
Air (%)	—	0.27	—	—	—	—	—	—	—	—
Water-reducing admixture, oz.	—	—	0	—	0	—	0	—	0	—
Mix weight, lb	—	—	3978	—	3978	—	3978	—	3978	—
Density, lb/ft ³	—	—	147.3	—	147.3	—	147.3	—	147.3	—
w/cm	—	—	0.53	—	0.53	—	0.53	—	0.53	—

Notes:

1. Batch weight = SSD weight / (1 – FMA).

2. Adjust weights to correct yield based on measured density.

produce adequate strength.

Fly Ash (Table 2.4, Mix #3)

Because fly ash is generally less costly than cement, the mix ingredient cost may be reduced if fly ash is substituted for cement. A water reducer is generally incorporated in mixes having fly ash. If fly ash is used, the fly ash to total cementitious material should generally be between 15 and 30%.

In Table 2.4, Mix #3 incorporates a water-reducing

admixture and the fly ash to total cementitious material is 28%. The table shows the effect on cement, aggregate, and water to produce a mix with similar absolute volume, w/cm, and slump as Mixes #1 and #2. In this discussion, it is assumed that the water reductions for Mixes #2 and #3 are similar, although incorporation of fly ash often promotes additional water reduction at a given slump.

The 28-day cylinder strength of Mix #3 may be similar to that of Mixes #1 and #2, and the set time may be longer. The early “in-place” strength and set time of fly

ash mixes should be tested for compatibility with the application. In cool or cold weather, the reduced cement content and inherent characteristics of many water reducers and fly ashes can cause excessive retardation. If use of an accelerator is contemplated, consider the use of Mix #1 after verifying that it will produce adequate strength.

Incorporation of fly ash, particularly Class F fly ash, increases the difficulty of producing concrete with relatively consistent air content. Frequent measurement of density, in addition to air content, is necessary to monitor air content and make necessary changes to the dose of air-entraining agent.

If uniformity of concrete color is a concern, the consistency of color and dependability of supply from the fly ash source should be guaranteed prior to use.

Fly ash can generally improve workability, pumpability, and finishability, especially in lean mixes, and also sulfate resistance (with Class F ash) and resistance to alkali-aggregate reaction.

Adjusting for Air Entrainment

Air-entrained mixes are proportioned using the same procedures as for non-air-entrained mixes. Table 2.2 relates w/c to strength and Table 2.3 relates w/c to exposure conditions for air-entrained concrete.

An air-entraining agent (AEA) is used to increase air content and this increases slump and volume (yield) and lowers unit weight (density). In order to correct mix yield and restore slump, it is necessary to reduce sand and water content. The reduction in water, if air content has been increased from 1 percent to 6 percent, is approximately 25 lb/yd³, and the reduction in sand is approximately 150 lb/yd³, compared with Mix #1 (Table 2.4).

Entraining air in concrete without adjusting the mix generally reduces strength. The reduction in water content to restore slump compensates in part for loss in strength, particularly in lean mixes having a strength of up to approximately 3500 psi. Above 3500 psi, it is generally necessary to increase cement content and, particularly if the specified strength exceeds 4000 psi, more closely control air content.

Constant technological refinement in production processes contributes to changes in the properties of cementitious materials, aggregate, and admixtures; these changes may promote significant increases in air content. Monitoring of air content should be continual, regardless of whether concrete is air entrained. This is important because, as previously discussed, strength reduction may result from an increase in air content. A simple method of monitoring air content is to weigh cylinders prior to capping and breaking, and record the results on cylinder strength reports.

For a concrete mixture with given ingredients, there is a relationship between air content and unit weight (density). Concrete suppliers should know this relationship. If there is no indication that the batching process was flawed, concrete should not be rejected for high or low air content unless measured density verifies that the measured air content is logical. If the relationship of density and air content is not logical, the air content should be remeasured after calibration of the air meter. It is expedient to use a calibrated air meter bucket to measure density before measuring air content.

Water Addition at the Jobsite

When water is added at the jobsite, be certain that the maximum w/c is not exceeded. This is the number one restriction on water addition because it is directly related to strength. The w/c should not be exceeded even if the slump when the concrete is delivered is lower than specified. Adding water to adjust slump should be closely monitored.*

Most specifications allow water to be added only once on the job—prior to discharge and when the slump is less than specified. The water added is limited to the amount required to increase the slump to the level specified in the mix design. During discharge, workability may be restored only by remixing without the addition of water.

When water is added, be very careful that the maximum allowable w/c is not exceeded. After adding additional water at the jobsite, then the drum should be turned an additional 30 revolutions or more if necessary at mixing speed. Discharge of the concrete should be completed within 1-1/2 hours or before the drum has revolved 300 revolutions, whichever comes first, after initial introduction of the mixing water to the cement and aggregates (not after water is added at the jobsite).

Because of unavoidable differences in delivery times, if a pour requires several loads of concrete, each truck may have a different slump, and jobsite slump adjustment, with the addition of water to a full load, should be considered part of the concrete production process. The concrete supplier and concrete contractor should agree on the maximum gallons of water that may be added per cubic yard, and this should be shown on each delivery ticket.

Set Time

To obtain consistently good quality concrete pours, set time should be predictable. This means that concrete loads should set in the order they are placed, and indi-

* As a rule of thumb, adding 1 gal. of water per cubic yard of concrete will increase the slump by approximately 1 in. and will reduce compressive strength by approximately 150 psi.



vidual loads should exhibit relatively uniform rather than “spotty” set. Set time may be measured using ASTM C 403 or the depression of a thumb.

Set time is related to:

1. Mixture ingredients, for example, the type and quantity of cement and other cementitious materials, and the type and dose of admixtures. Contractors should be aware that combining a water reducer, or retarder, with a mid-range or high-range water reducer may cause excessive variation in set time and excessive set retardation. Also, variation in air content may result in “spotty” setting. Unpredictable or “spotty” set promotes blisters and delamination of machine-troweled slabs. Excessive retardation promotes plastic shrinkage cracking.
2. Concrete temperature and ambient temperatures. Ambient temperatures include those of air,

substrate, forms, and embedded items such as steel reinforcement.

3. Dimensions of the concrete placement. This may vary from a relatively thin slab that is greatly affected by ambient temperatures to a relatively massive footing that is much less affected by ambient temperatures.

Before finalizing a bid or signing a contract or purchase order, the concrete purchaser and concrete contractor should estimate the set time of proposed mixtures with the concrete supplier to determine compatibility with the use and temperature conditions at time of placement, and revise mixtures as necessary. Refer to the section in Chapter 3 entitled “Temperature of Concrete—Hot and Cold Weather Concreting,” for additional information.

Chapter 3:

The Concrete Specification

Specifications are the written description of the project and drawings are the graphic depiction of the project. Together, they are referred to as the contract documents. They complement each other and are equally important. The technical language and abbreviations used in specifications often makes them difficult to understand. It is often essential to forward a copy of the specification to the ready-mix supplier so there is no confusion about what is required. Overlooking or misunderstanding any aspect of the specification could result in significant financial consequences and penalties.

Specifications are written by design professionals, which include architects, engineers, and specifiers. In a traditional arrangement, the owner hires the architect, and the architect selects the engineers and the specifiers to develop the specification. The architect is the owner's representative in discussions and addresses questions related to the project. On a design-build project, the architect and engineer are hired by the general contractor.

Sources for Concrete Specifications

Major sources for the content of a project specification are the American Concrete Institute (ACI), the American Society for Testing and Materials (ASTM), and the American Association of State Highway and Transportation Officials (AASHTO). Many governmental agencies (such as a state's department of transportation, the Army Corps of Engineers, or the Federal Aviation Administration) have their own provisions.

The five-part *ACI Manual of Concrete Practice (MCP)* contains ACI specifications, standards, guidelines, and committee reports on concrete materials and properties, design and construction, and structural analysis. The ACI

MCP is published annually. Documents within the *MCP* are reviewed and updated on a periodic basis. The review and update process reflects the evolution of the construction industry. Project specifications require contractors to use the most recent version of ACI documents. For example, the full name of ACI 318 is ACI 318-02, which means it was updated in 2002. Both ACI 318, "Building Code Requirements for Structural Concrete," and ACI 301, "Standard Specifications for Structural Concrete," are referenced in almost all specifications. Both of these documents reference other ACI and ASTM standards and specifications.

ASTM provides standards and specifications for cement, cementitious materials, concrete, concrete aggregates, admixtures, and material testing. Cement is under the jurisdiction of ASTM Committee C 1, and concrete, concrete aggregates, and admixtures are under the jurisdiction of ASTM Committee C 9. ASTM standards and specifications are reviewed and updated every 5 years. Specifications require that contractors use the most recent version of ASTM documents. For example, the full name for ASTM C 94 is ASTM C 94-98, which means it was updated in 1998. ASTM C 94, "Standard Specification for Ready Mixed Concrete," is the cornerstone of the ready-mix concrete industry. ASTM standards for cement, aggregates, admixtures, ready-mixed concrete, and materials testing are referenced directly in the project specification in addition to being included in ACI 301 and ACI 318. Others are simply referenced in ACI 301 and ACI 318.

AASHTO standards are usually referenced in state department of transportation specifications. Most of the AASHTO standards are the same or similar to their counterparts in ASTM, but there can be differences between them. Many states modify the standards for their specific needs. Sometimes the differences are

the purpose of allowing the use of local materials that don't meet a national standard but have an established record of satisfactory performance. An AASHTO or state department of transportation standard may appear to be the same as the ASTM or ACI standard, but they should be read carefully to avoid unfortunate surprises.

The Portland Cement Association (PCA) is highly regarded by the specifying groups and makes a great contribution toward the development of standards for concrete. PCA's recommendations for standards and construction practices, contained in a wide range of literature, will often be the basis of a specification.

The American Society of Concrete Contractors (ASCC) is composed of concrete contractors, architects, engineers, suppliers, and others with an interest in the concrete industry. The primary focus of this group is to "enhance the capabilities of those who build with concrete." The ASCC acts as the voice of the concrete contractor to the concrete industry on practical and technical issues.

The National Ready Mixed Concrete Association (NRMCA) also has a highly respected staff that is active in the national standards organizations and has numerous publications available for reference. In some areas, local concrete associations have developed recommendations for concrete that may be very helpful to concrete contractors.

Ready-mix suppliers and their vendors are a valuable resource for locating and understanding documents referenced in specifications.

Specification Categories **Prescriptive, Performance, Hybrid**

Prescriptive specifications dictate concrete mix specifics to ready-mix producers, such as cement content, minimum compressive strength, w/c , slump, and other variables.

Performance specifications require that ready-mix producers achieve target compressive strengths and entrained air. This method allows the ready-mix producer the widest range of choices when designing concrete mixes.

Hybrid specifications are a combination of both prescriptive and performance requirements. Confusion often occurs if various aspects of the specification do not seem to match.

Concrete producers will generally identify the most rigid requirement of the concrete specification and bid accordingly. Typically, the most rigid requirement will be the most expensive method to produce a concrete mix.

Bidding the most rigid requirement is stipulated in most building codes, including the BOCA National

Building Code, 1987 edition, Section 101.5, Other Regulations, which states: **"When the provisions herein specified for health, safety and welfare are more restrictive than other regulations, this code shall control; but in any case, the most rigid requirements of either the building code or other regulations shall apply whenever they conflict."**

The contractors should ensure that the producer has the necessary information about the uses of the mix so that the best-possible concrete can be produced for the situation.

Items to Confirm in the Specification **Strength**

Most specifications include a specified strength, designated by the symbol f'_c , which is measured in megapascals (MPa) or pounds per square inch (psi). Unless otherwise specified, f'_c is the 28-day strength of cylinders molded, cured, handled, and tested in accordance with ASTM C 31 and C 39 (refer to the section entitled, "Compressive Strength Tests (ASTM C 31 and C 39)" in Chapter 2). Compressive tests at 7 days are used to provide an indicator of strength development. Compressive tests at 56 days measure the strength contributed by cementitious materials that gain strength more slowly than cement.

The methods of evaluating cylinder tests for strength are described in ACI 301 and ACI 318. There are two cardinal requirements:

- The average of any three successive tests must equal or exceed the specified strength.
- No test may fall below the specified strength by more than 500 psi.

A test is defined as the average of two cylinders made from the same sample (refer to the section entitled, "Reported Low Cylinder Strengths" in Chapter 11).

A statistical formula in ACI 318 is used to calculate the average strength required to comply with the specified strength. The statistical measure of the amount the individual tests vary from the average of all of the tests is the "standard deviation." The greater the variation of the test results—that is, the greater the standard deviation—the higher the average strength must be. For acceptance testing, the primary factors affecting the amount the tests will vary are:

- Quality control at the ready-mix plant.
- Control of water addition on the job.
- Compliance with the testing procedures for concrete cylinders, starting with controls at the jobsite. Specifications usually require the contractor to provide temperature-controlled storage for the compressive strength test specimens, which are referred to as cylinders.

For example, with excellent quality control, the average strength required for an f'_c of 4000 psi concrete mix might be 4400 psi. With lesser control, the average under the ACI 318 formula might be higher than 5000 psi. That range may represent a difference in cementitious requirements of up to 100 lb/yd³—an added cost to the contractor because of inadequate concrete quality control or use of nonstandard concrete field testing procedures.

ACI 318 rewards good quality control by allowing lower average strengths (synonymous with “more economical mixes”) to meet the strength specification. The contractor can help greatly by controlling water addition and especially by monitoring jobsite testing.

ASTM C 94, Section 16.2, states, “Tests of concrete to determine compliance with the Specification shall be made by a certified ACI Concrete Field Testing Technician, Grade I or equivalent. Equivalent personnel certification programs shall include both written and performance examinations, as outlined in ACI CP-1”

Nonstandard concrete cylinder test specimens are a serious problem in the concrete industry. Some general contractors do not appreciate the strict methods prescribed for making concrete compressive test specimens and consequently create serious problems for themselves, the concrete contractor, the ready-mix supplier, the specifier, and the owner. Common deficiencies include tops extremely rough or out of level, and tops not covered with lids or plastic curing bags. Other problems include cylinders that are not delivered to the test lab within the 24- to 48-hour time frame and cylinders delivered without accompanying paperwork listing essential information such as: concrete slump, air content, temperature, project name, date cast, concrete supplier, or field technician.

It is a serious dilemma for concrete test labs to deal with compressive test specimens that have rough and out-of-level tops. One of the few options is to first saw off one or both ends of concrete test cylinder specimens so the ends are perpendicular to the sides. If this is not done, actual compressive strengths might only yield one-fourth of the potential compressive strengths. The additional cost for sawing numerous cylinders is not welcomed by the firm paying for the compression testing.

If the concrete contractor employs an ACI Certified Concrete Field Testing Technician, Grade I, it is wise to cast companion cylinders made from the same load of concrete sampled by the testing laboratory or the general contractor. Inspection and specification enforcement is not a one-way street—inspecting the inspection procedures often improves the quality of testing.

For most concrete mixes, the concrete supplier should

know the relationship between 7- and 28-day strengths. A 7-day “target” strength should be established that, if met, removes any concern about the adequacy of the 28-day strength. In the absence of data supporting a better estimate of 7-day “target” strength, use 1000 psi below the specified 28-day strength.

If the average of any three consecutive strength tests is more than 500 psi below the “target” strength, the cement content should be increased 50 lb/yd³ or the admixture type and dose should be changed (in the absence of flawed batching or testing). Subsequent test data may justify further mixture revision.

Contractors should promote specification of 7-day “target” strength and establishment of a method for immediately providing 7-day test data to the concrete contractor and concrete supplier, regardless who pays for the testing. Too often this does not happen, and the job suffers because correction of problems takes too long.

Early Strength Requirements

Occasionally a specification will call for high-early-strength concrete for a special application. If high-early-strength cement (Type III) is specified, the contractor must contact the ready-mix supplier, as availability may be a problem. The contractor should check whether alternatives may be used such as adding 100 lb of cement per cubic yard, or adding an accelerator. If an accelerator is used, a nonchloride accelerator is recommended for reinforced concrete. Whenever specialty cement is specified, the contractor should notify the ready-mix supplier immediately. Type II and Type V cements may not be available, and Type IV cement has not been manufactured for many years.

Flexural Strength

Flexural strength is sometimes specified for structures for which the design is based on the bending strength of the concrete. Flexural strength is often specified for airport pavements.

If flexural strength is to be measured with beams, the relationship between flexural strength (measured in accordance with ASTM C 78) and cylinder strength should be determined under laboratory conditions. In the event of lower than expected flexural strength, it should be accepted that companion cylinders or cores, interpreted in accordance with ACI 318 or ACI 301, may be used to determine strength adequacy. This is important because beam tests sometimes provide apparently inconsistent results; for example, the beam strength at 3 or 7 days may be higher than beam strength at 28 days.

Water-Cementitious Material Ratio

Conditions for which the concrete’s maximum w/cm are specified are exposure to freezing and thawing.



deicing chemicals, sulfates and abrasion. Other conditions where a low w/c might be specified are when low permeability is needed to prevent moisture migration through floors and walls, or to provide protection against corrosion of reinforcing steel.

When a maximum w/c or w/cm is specified, the compressive strength obtained will often be higher than the compressive strength required for the structural design. That is why a compressive strength specification may be inadequate where durability is the primary concern. Similarly, a w/cm specification may be uneconomical where durability is not critical.

Although the mix design process is explicit, many are confused regarding the w/cm aspect of the specification. Perhaps the contractor and ready-mix supplier don't know why the designer specified a certain w/cm . It could have been, for example, to prevent moisture migration through the concrete and reduce the failure probability of an impervious membrane flooring system.

What the contractor does realize is that a low w/cm mix design is expensive to purchase and challenging to place. The contractor may have been involved in similar projects that did not require such a low w/cm specification.

The contractor may not have had time to petition the designer for substitution of a compressive-strength performance mix during the bidding process, and consequently violated the w/cm specification. The potential consequence for overlooking w/cm specification or neglecting to inform the ready-mix supplier about it could be significant. If an impervious flooring membrane fails, for example, and it is discovered that the concrete did not meet the w/cm specification, both the contractor and the ready-mix supplier could be financially liable.

Minimum Cement Content

When a minimum cement content is specified along with a strength requirement, both specifications must be met even if the specified strength can be obtained with less cement than specified. If the minimum cement content isn't enough to meet the strength specification, more cement will have to be added. Note, however, that higher cementitious contents tend to increase shrinkage and slab curling. When the specified strength doesn't seem appropriate for the minimum cement content required, check with the specifier to clarify the intent of the requirement.

Because fly ash is now extensively used, minimum cement contents may have another meaning. ACI 318 and ACI 211.1, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete," allow fly ash, slag, and other pozzolans to be counted as part of the total cementitious content (refer to the section entitled, "Other Cementitious Materials" in Chapter 2).

When a pozzolan is used, the w/c is computed as a w/cm . The pozzolan is a part of the total content of cementitious material, and w/cm is the equivalent of w/c for a straight portland cement concrete mix. For example

Mix 1: 550 lb cement; 270 lb water
 $w/c = 270 / 550 = 0.49$

Mix 2: 425 lb cement; 125 lb fly ash; 270 lb water
 $w/cm = 270 / (425 + 125) = 0.49$

The w/cm for both mixes is the same because the total cementitious content and the water content are the same.

When the specification includes a minimum cement content, make sure it is clear whether or not cementitious materials other than portland cement (such as fly ash) can be included in this minimum. While the major specifications accept fly ash this way, not all specifiers will have that intent. Whether or not fly ash mixes may be used will usually affect the economy of the mix. It is important to confirm fly ash acceptance by the specifier before bidding a job. If fly ash is acceptable, the specification should reference ASTM C 618, "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete." (Refer to Chapter 2 for information on the effect of fly ash on the mix.)

Silica fume and blast-furnace slag can also become a part of the cementitious content. These are used primarily to produce high-strength concrete and improve corrosion resistance by reducing the permeability of the concrete. If silica fume is being used, the specification should reference ASTM C 1240, "Standard Specification for Use of Silica Fume as a Mineral Admixture in Hydraulic Cement Concrete, Mortar and Grout." (Refer to Chapter 2 for information on the effect of silica fume [also sometimes called microsilica] in the mix.)

Slump

The specified slump limits are intended to be high enough for adequate placeability but low enough to prevent segregation, excessive bleeding, or premature finishing of wet concrete. Moderate slumps for most work might be approximately 3 to 4 in. In lower-slump mixes (2 to 4 in.), the tolerance is ± 1 in.; in higher-slump mixes, (more than 4 in.), it is $\pm 1\frac{1}{2}$ in. Sometimes the specification for slump is written as a "maximum" or "not to exceed" requirement, meaning there is no plus tolerance. The value of the slump test is primarily to monitor the uniformity of the concrete from one load to another.

Be sure the maximum slump is adequate for your method of placement. If it isn't, adjustments to the

mix will have to be made with the specifier's approval. Possible changes include increased water content with proportionately increased cement content or the addition of a superplasticizer.

If the concrete is going to be pumped, clarify where the slump test will be made—before or after the concrete is pumped. ASTM C 94, "Standard Specification for Ready-Mixed Concrete," states that the test is made before pumping unless otherwise specified.

Refer to the section in Chapter 2 entitled, "Water Addition at Jobsite" for recommendations related to jobsite slump adjustments.

Air Entrainment

Air entrainment should always be specified for concrete exposed to freezing and thawing. If it is exposed to freezing and thawing in the presence of deicers, the concrete will scale—not probably or maybe, but *will* scale—unless the concrete is adequately air-entrained.

If the specification happens to omit air entrainment where it should be used, call it to the specifier's attention.

For severe weather exposure, the air content should be 5 to 8 percent in mixes with 3/4- to 1-in. maximum size aggregate. Air content is increased for smaller maximum-sized aggregate and may be reduced slightly for larger-sized aggregate—but should never be less than 4 percent if the concrete will be exposed to freezing and thawing or deicers. Air entrainment may be used for other purposes also, often at somewhat lesser air contents.

If a slab incorporating normalweight concrete is to have a dense, polished surface by means of trowelling, the concrete mix should not have an air-entraining agent because this will generally promote blisters and delamination, regardless of equipment and finishing technique used.

A slab incorporating structural lightweight concrete generally uses air entrainment in the mix to control density and segregation. By using "walk-behind" machine floats and trowels it is possible to consistently provide a relatively dense, polished surface without blisters or delamination. Note that the use of rider-operated floats with dual non-overlapping pans allows premature floating because these machines apply less pressure to the concrete. This has resulted in delamination of slabs incorporating non-air-entrained normalweight concrete and also air-entrained structural lightweight concrete. If use of rider-operated pan floats is planned, consider doing it after floating with a "walk-behind" machine. For more details, refer to ACI 302-04.

Refer to the section in Chapter 2 entitled, "Adjustment for Air Entrainment" for additional information on air-entrained concrete mixtures and control of air content.

Chemical Admixtures

The specification should contain a reference to ASTM C 494, "Standard Specification for Chemical Admixtures for Concrete," and to other ASTM and AASHTO specifications where applicable.* Having the freedom to use various admixtures is extremely important to the ready-mix producer and the contractor. Admixtures can affect the quality and the economy of the concrete mix and the concrete placement methods available to the contractor.

Water reducers, retarders, accelerators, water-reducing retarders, water-reducing accelerators, and high-range water reducers (superplasticizers) are used routinely. If the specification doesn't clarify which may be used, it is necessary to confirm their acceptability in writing with the specifier, however.

Many specifications restrict or prohibit the use of calcium chloride out of concern for corrosion of the reinforcing steel. Some admixtures, particularly water-reducing accelerators, contain calcium chloride in amounts that may exceed specification limits. For high early strength, consider using high-early-strength cements (Type III) or additional Type I cement.

Specifiers not familiar with superplasticizers may be uncomfortable with the high slumps at which superplasticized concrete is placed. It may be necessary to explain the difference between the character of high-slump superplasticized concrete and high-slump concrete produced by adding water. That is, superplasticizers result in high-slump concrete without any of the problems associated with excess water. The superplasticized mix is more homogeneous and far less prone to segregation. Since the slump specification will probably have been written for a conventional mix, the typical superplasticized mix will be placed at a slump approximately 4 to 5 in. higher than specified. That relationship should be confirmed and clarified with the specifier.

Delivery Time for Ready-Mixed Concrete

Unless special conditions are involved, the maximum delivery time (the time between when water and cement were combined in batching the mix to the time of completion of discharge on the job) is specified as 90 min or 300 revolutions of the mixer drum. A shorter time, usually 60 min, is sometimes specified for hot weather.

The same delivery time is not as critical for all concrete mixes or conditions. Differences in cement content or water content, the temperature of the materials, the ambient temperature, the use of retarders, and fly ash

*Another helpful reference is ACI 212.3R, "Chemical Admixtures for Concrete."

as part of the cementitious material will all affect the time during which the concrete remains workable in the mixer. For that reason, ASTM C 94 states that the time limit may be waived “if the concrete is of such slump . . . that it can be placed, without the addition of water, to the batch.”

If you and the specifier can agree in advance that the specification will be enforced in that manner, the methods for extending setting time can be used effectively to reduce construction costs.

For more information, refer to the section in Chapter 2 entitled, “Water Addition at Jobsite.”

Temperature of Concrete—Hot and Cold Weather Concreting

For hot-weather concreting, a maximum concrete temperature of 90 F is often specified. High temperature adversely affects the concrete mix in three ways:

- Increases the required water content in the mix for the same slump, thereby reducing the strength.
- Shortens the setting time.
- Increases the amount of air-entraining agent needed to produce a specified air content. (It is important to adjust the dosage rate of air-entraining agent to compensate for high and low temperatures.)

There will be added costs in hot weather if a concrete temperature specification is to be met. Cooling the mix water and cooling the aggregate stockpiles is a start. The replacement of a portion of the mix water with crushed ice or injection of liquid nitrogen into the mix water or into the truck mixers are commonly used procedures. To compensate for the loss of strength, it may be necessary to add some cement.

In addition to cooling, much of the effect of high temperature on strength and setting time can be offset by using a Type II cement with the optional low heat of hydration option described in ASTM C 150, with a retarder, or by replacing some cement with fly ash or slag to reduce the heat of hydration.

Often it requires a focused effort of the general contractor, concrete contractor, ready-mix supplier and vendors supplying the ready-mix supplier to approach the designer in a diplomatic manner to bring about a change in a specification.

For cold-weather concreting, a minimum concrete temperature is often specified. This temperature will depend on air temperature, the minimum dimension of the placement, and the ability to maintain concrete temperature after placement. Thin slabs are the most vulnerable to cold-weather damage, and the minimum concrete temperature, as delivered, should be 60 F or higher. Concrete temperature is raised by heating the mixing water, and also the aggregate, if necessary.

In cold weather, concrete must have time to set before it can gain sufficient strength to prevent damage from freezing. Conditions that justify the use of an accelerator also justify additional modifications to the concrete mix. For example, fly ash should be replaced with cement, and the water-reducing admixture may be eliminated or the dose reduced. Also, the cement quantity may be increased or the cement changed to Type III. These modifications will allow a reduction in the dose of accelerator, or eliminate the need for accelerator. The cost effectiveness of the various mixes should be compared.

For additional information on hot- and cold-weather concreting, refer to ACI 305, “Hot Weather Concreting,” and ACI 306, “Cold Weather Concreting.”

Determining the Most Rigid Criteria of the Concrete Specification

Concrete technologists are taught to identify the most rigid requirement of the concrete specification and bid accordingly. Generally speaking, the most rigid requirement will be the most expensive method to produce a concrete mix.

Assume a contractor is bidding a 1000 yd³ concrete slab on grade floor. The specification requires concrete with a 0.41 *w/cm*, no air entrainment, a minimum cementitious materials content of 564 lb/yd³, and a minimum compressive strength of 4000 psi at 28 days.

Of the three mix design criteria in this specification, “the most rigid requirement” is the 0.41 *w/cm*, and it therefore takes precedence.

Chapter 4:

Foundations

A foundation is the base upon which a building, structure, or component is constructed. It includes the earth and rock on which the base is placed to properly distribute the weight of the structure itself (dead load) and imposed loads on and in the structure (live load). Most foundations are concrete because of its relatively low cost, long life, high compressive strength, and resistance to deterioration.

Construction of the foundation must be planned just as carefully as the foundation was designed. Some foundation sites may require dewatering during construction, the sides of the excavation may have to be braced, and adjacent buildings may have to be underpinned.

While the type and size of a structure will partly determine the type of foundation, the foundation itself is very much affected by the surface and subsurface conditions of the building site.

The Ground Below

Soil provides the foundation bed that most structures are built on. Soil includes gravel, sand, clay, loam, or silt in its natural undisturbed condition. Soil types and subsurface conditions are an important factor in determining the type of foundation selected.

Over time, structures settle to some degree unless they are founded on rock. The soil conditions beneath a structure determine the amount of settlement. Excessive or uneven settlement can cause cracks in the foundation and damage to the building.

Foundations can be built directly on soil that has enough load-bearing capacity to carry the building's weight. Foundations require excavation; the depth varies with type of structure, climate, and soil conditions. Even the simplest slab on ground needs to have the grass and sod removed to prevent uneven settlement as a result

of decaying organic materials. At times, the height and size of the structure or the soil conditions require that piles be driven deep into the ground or piers drilled to support the building.

Solid rock is one of the best foundation materials. In preparing a rock bed, loose and decayed portions should be cut away and the rock leveled. Any fissures or seams in the rock should be filled with concrete or grout. Sloping surfaces should be stepped with concrete to make a level footing.

Most construction, however, takes place on soil or engineered compacted earth fills rather than rock.

Bearing Capacity

Bearing capacity is the ability of the soil to support weight without excessive settlement. The bearing capacity of a soil depends on its composition, the degree to which it is confined, and the amount of moisture it contains.

A number of different layers of earth (strata) exist at most building sites. The bearing capacity of each layer can vary. Excavation of some of these layers may be required to reach soil with enough bearing capacity to support the foundation load.

Some soils are stronger than others. One of the strongest is compacted gravel mixed with sand or clay (known as hardpan), which provides excellent bearing for most foundations. Compacted loam (sand and silt) of considerable depth also provides good bearing. Clay is an uncertain soil since its performance can vary with moisture content—when dry it is very firm, but when wet, it can expand and become slippery and unreliable. Dry sand, or wet sand when prevented from spreading, is generally acceptable. Porous sandy soils are easily washed away by running water, however. Marshy and “quick” soils generally require pile foundations.

increasing construction difficulty and expense.

Because there are so many types of soils with different characteristics, proper site investigation is necessary. Soil types may even vary across a site. For most structures, a soil investigation by a geotechnical consultant is strongly recommended.

Geotechnical Investigations

No matter how simple a job may be, it is essential to know the soil conditions that will be encountered. Soil tests are recommended for all but the simplest of jobs. Generally, a testing laboratory or geotechnical engineer conducts the tests. Except for the simplest structures, the bearing capacity of soil is usually determined by borings, test pits, and laboratory testing of soil samples.

Open test pits are considered a reliable method for shallow exploration. With this method, the geotechnical engineer can see the earth layers in their natural condition.

Heavy construction projects and large buildings that require deep excavation and major foundation systems call for extensive laboratory soil testing. When subsurface soil samples are required, power augers and drilling rigs are used to bring up samples and to locate the elevation of the water table.

For many residential and light construction buildings, extensive soil investigations are not required where the foundation excavation is based on established practice in the area. If a building site is located on fill, however, both the quality of the material and the degree of compaction need to be determined. Poor fill material or poorly compacted fill do not provide an adequate foundation base. In such locations, construction should not start until the poor fill is removed and the ground is excavated to undisturbed soil, the fill is properly compacted, or additional support, such as piling or drilled piers, is provided. A mat or raft foundation is another alternative for building on an unstable site. A structure built partly on natural soil and partly on fill may settle differentially and crack.

Another problem soil that is commonly encountered these days is expansive clay. If the potential for expansive clays exists, the site should be evaluated by a geotechnical engineer.

When reviewing a geotechnical engineer's report prior to starting construction (**and you should review the report**) compare the appearance of the site to the descriptions in the report. If they don't appear to match up (for example, if some excavation has been done since the soils investigation), pointing out these inconsistencies to the owner or engineer could save everyone a lot of time and money later.

Compaction

Compaction is the consolidation of soil by vibrating, tamping, rolling, or adding temporary weight. Soil compaction is commonly required for building foundations, slabs on ground, driveways, and sidewalks. It should be noted that the quality of a slab on ground depends upon the quality of subgrade preparation. During construction, the soil is often disturbed and loosened by excavating, grading, or trenching. This loosens the soil mass and requires recompaction to re-establish a more solid mass of soil.

The primary purpose of compaction is to reduce air voids, but it also can remove excess moisture. Proper compaction reduces the amount of settling and increases the stability of the soil and thus its loadbearing ability. The chances of frost heave in compacted soil are reduced because penetration of water into voids in the soil is minimized.

For compaction purposes, soils can be classified into two broad groups:

- Granular soils (mainly sands and gravels), and
- Cohesive soils (mainly silts and clays).

Moisture content is the most important factor in efficient soil compaction because it acts as a lubricant, helping particles move closer together under compactive effort. The optimum moisture content for a particular soil depends on its composition. For any soil, there is only one optimum moisture content at which maximum soil density is achieved by a certain amount of compaction.

Major or critical construction projects require the advice of a geotechnical engineer. The following technique, however, can be used to make a rough estimate of whether the soil contains the right amount of water for compaction.

Take a handful of the soil and squeeze it into the size and shape of a tennis ball. Drop it on the ground from a height of about 1 ft.

- At optimum moisture content, the ball holds together, and when dropped, breaks into a few fairly uniform pieces.
- If too dry, the soil does not form into a ball at all. Moisture should be added before compaction.
- If too moist, the ball will leave traces of moisture on the fingers, and when dropped, does not break apart (unless the soil is very sandy). The soil should be allowed to dry before compaction.

Because of the importance of proper moisture content, compaction should rarely be done in rain or snow. On the other hand, hot, dry weather is fine as long as sufficient water is available.

In fills, the thickness of the layer of soil is important. The thinner the lift (or layer), the better the compaction.

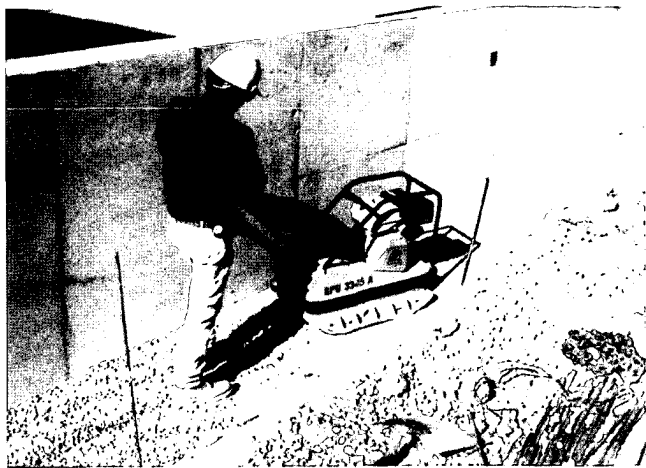


Fig. 4.1 — Vibratory compactor. (Photo courtesy of Wacker Corporation.)

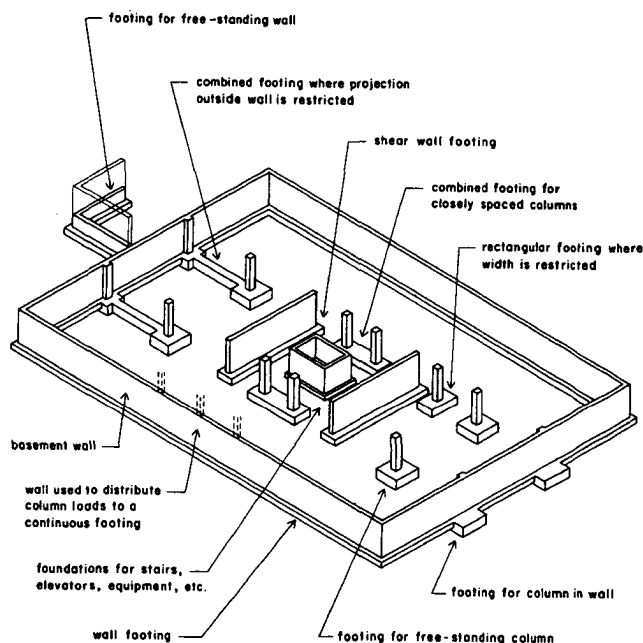


Fig. 4.2 — Typical elements of shallow bearing foundations. (With permission from *Simplified Design of Building Foundations*, by James Ambrose, John Wiley & Sons.)

In most cases, the normal lift depth specified is 6 to 12 in., depending on the efficiency of the compaction equipment. Each lift must be compacted to some percentage (typically 95% or more) of maximum density before the next lift is placed.

The three major ways to compact soil are:

- Static force—a heavy roller squeezes or kneads soil particles together.
- Impact force—a ramming shoe alternately strikes and leaves the ground at high speed, or a heavy weight is repeatedly dropped on the soil.
- Vibration—high-frequency vibration is applied to the soil through a steel plate.

Large areas (for example, underneath pavement) are usually compacted by mobile equipment such as

sheepsfoot rollers, static rollers, vibratory rollers, or pneumatic-tired rollers. Smaller areas and areas around buildings can be compacted by smaller-size mobile equipment and hand-held, power-operated tampers and impactors/rammers (Fig. 4.1).

Granular soils are best compacted by vibration. Cohesive soils (clays) are best compacted by impact force (a rammer) or by pressure that is maintained for some time (such as when a soil surcharge is used). Combinations of impact force and vibration also are used: for example, vibratory rollers combine static weight with vibration to achieve compaction.

In choosing the right compactor for the job, think about soil type, physical conditions of the jobsite, compaction requirements, and which equipment will do the job most economically.

Basic Foundation Types

The two types of foundations are shallow bearing foundations and deep foundations.

The most common types of shallow foundations are continuous spread footings for walls and spread footings for columns. For lightweight buildings and heavier buildings on good loadbearing soil, the foundations normally consist of column footings or foundation walls (Fig. 4.2). The footings spread the load over a wide enough area for the soil to carry it safely.

Tall, heavy buildings with deep basements and heavy column loads, however, require deep foundations. Deep foundations are also required when the soil the foundation will bear on is not strong enough to carry the load or has weak materials beneath it. Basic types of deep foundations are piles and drilled piers.

The type of foundation chosen for a particular structure depends on the size of the structure, the concentration of building loads, the depth from the ground surface to bearing of adequate capacity, the type of subsurface material, the comparative cost, closeness of other buildings, and the type of equipment available.

The foundation of a building often consists of spread footings beneath the interior columns and either local footings or continuous wall footings beneath the exterior columns.

For residential construction, most building codes specify minimum requirements for foundations based on the number of floors to be supported. Typical requirements are shown in Table 4.1.

The area of a footing base must be increased until its safe bearing capacity exceeds the design loads on it. It is not necessary to eliminate all settlement, but it is necessary to make sure that any settlement that does take place will be reasonably uniform.

The bottom of a footing should always be below

Table 4.1 — Minimum Requirements for Residential Foundations (from Uniform Building Code)

Number of floors supported by the foundation	Foundation wall thickness (inches)		Footing width (inches)	Footing thickness (inches)	Depth below undisturbed ground surface (inches)
	Concrete	Masonry			
1	6	6	12	6	12
2	8	8	15	7	18
3	10	10	18	8	24

the frost level. Frost penetration varies with locality, from very shallow in southern states to 2 to 3 ft in the midwest to 4 to 5 ft in northern states. During and after construction, special precautions should be taken to prevent freezing of soil below the footings. Never build on frozen soil. Footings placed above the frost line or on frozen soil are subject to soil heaving (sometimes called frost heave). Soil heave occurs as the soil freezes and expands, resulting in the building moving upward. When the soil thaws, the structure drops down again. This up-and-down movement can damage the foundation as well as the structure it supports. If a job must go forward and the ground is frozen, consider using ground heating systems where a network of heating tubes is laid out under an insulating blanket. Ground heating systems can thaw the ground in a few days.

Winter work in areas where freezing occurs requires protection of both the ground and the concrete foundations and walls. The protective blankets used to keep the concrete from freezing can also be used to protect the ground and keep it warm. These blankets can be pulled up as concreting progresses.

Interior footings of a building may be designed shallower than the exterior wall footings because once the building is finished, they do not face severe exposure. During winter construction, however, these footings may be exposed to freezing, and the contractor should call this to the attention of the engineer, suggesting that these footings be carried to the same depth as exterior footings. Remember also that concrete cures more slowly in cold weather, so stripping of forms and backfilling around the foundation should be delayed.

Where a structure or the soil conditions would require an excessive spread of the footing base to carry the load, drilled piers or driven piles are used. If a pile is driven so that its lower end rests on rock or a hard stratum, the loading is limited by the strength of the pile as a column. Many piles are not driven to rock. In that case, the load is carried by the friction of the earth along the sides of the pile.

Determining the depth and size of the footings

is always the responsibility of the engineer, and the contractor should not make changes without the engineer's approval. It is, however, acceptable for the contractor to ask questions and, in discussions with the engineer, to review the constructibility of the foundation design. These discussions can benefit the designer, the contractor, and the building owner by making construction easier and less costly.

Wall Footings

A wall footing consists of a continuous slab strip at the bottom of a wall with a width larger than the wall thickness (Fig. 4.3(a)). Bearing-wall footings are reinforced with steel bars. The main reinforcement (structural reinforcement) perpendicular to the length of the wall carries tension, while that parallel to the length of the wall prevents shrinkage cracking. This latter reinforcement is often called temperature steel.

Independent Isolated Column Footings

The most common spread footing (Fig. 4.3(b)) consists of a rectangular or square slab of constant thickness. Reinforcing bars are placed near the bottom of the footing and run in both directions.

Combined Footings

Combined footings support two or more columns (Fig. 4.3(c)). It is sometimes necessary to support a column within the building line on or near the edge of a property line. The nearest interior column is usually selected, and a combined footing is constructed under both columns.

Combined footings also are used when the distance between adjoining columns is relatively small and it becomes more economical from a construction standpoint to build a combined footing.

Cantilever or Strap Footings

These are similar to combined footings except that the footings for exterior and interior columns are built independently and joined by a strap or tie beam (Fig. 4.3(d)).

Pile or Pier Foundations

This type of foundation (Fig. 4.3(e)) is essential when the supporting soil has structurally unsound layers of material to a considerable depth. The piles may be driven to solid bearing on rock strata or hardpan or deep enough into the soil to develop the capacity of the pile through skin friction (friction between the surface of the pile and the soil against it). The type of piling used will depend on ground conditions revealed by the test borings.

Piles can be precast reinforced or prestressed concrete

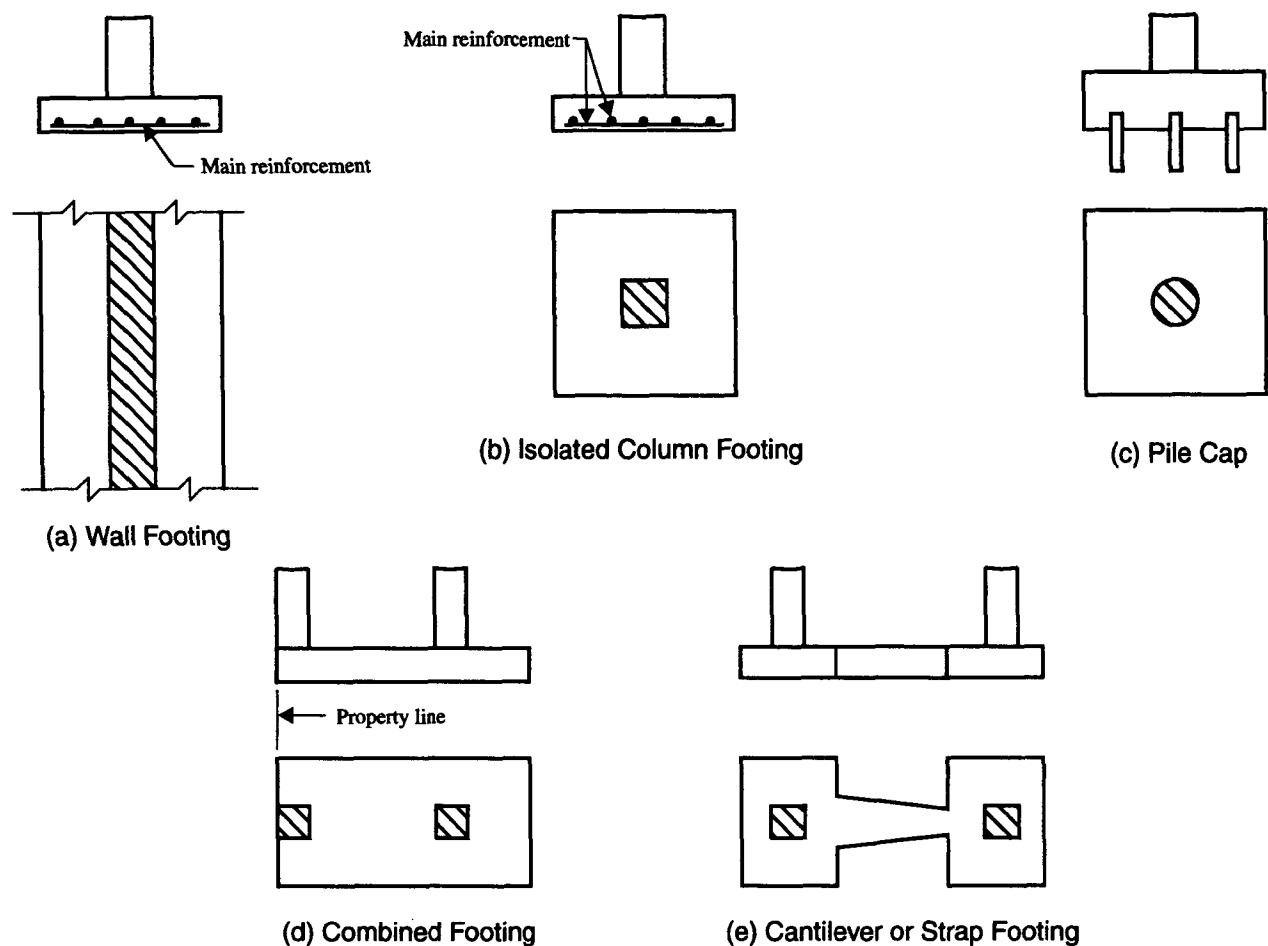


Fig. 4.3 — Basic foundation types.

members that are driven into the soil. Piles may also be made of steel or treated timber. Piles may be small “pin piles,” perhaps 3 in. in diameter, or much larger piles up to several feet in diameter.

Alternatives to the driven pile include the caisson of relatively small diameter, consisting of a shell that is forced into the ground as soil is excavated from inside the shell. Another is the drilled-in pile or pier, where a hole is drilled through soil to firm bearing and then filled with concrete.

Mat, Raft, or Floating Foundation

These types of foundations are used when the allowable bearing capacity of the soil is very low to great depths, making pile foundations uneconomical. The foundation substructure is spread over the entire area of the building so that the superstructure is theoretically floating like a raft on soil.

Raft foundations may be flat slabs of plain (unreinforced) or reinforced concrete, beams or girders with a slab underneath, or beams or girders with a slab on top.

Groundwater Control

The influence of groundwater should be considered in the building of foundations and whenever excavation is going to go much below the surface.

The water held in the ground is called groundwater. The level at which groundwater is encountered is called the water table. Groundwater levels can be easily established by observing the water levels in bore holes at the site. These levels may fluctuate seasonally.

Both surface water and groundwater that may interfere with building work need to be removed from the site. Surface water can be drained. Groundwater can often be removed the same way, except it requires greater planning. Sometimes pumping and dewatering techniques are required. Compare the maximum possible level of groundwater (the highest possible water table elevation) to the bottom of the excavation to find the level below which groundwater must be drained (how much the water table must be lowered). Drainage channels and pipes can be installed to move the water to an outlet that is lower than the bottom of the excavation or to a sump pit where the water can be pumped out. This

same principle is used in laying drainage tile around a building foundation to keep water away from the walls of the building during its operation.

During construction, there are two other principal methods of handling water and removing it from the excavation. One is to use pumps to keep the excavation dry. The other is to lower the water table in the area of the excavation by installing a series of well-points and extracting the water by pump (Fig. 4.4). The well-point is a hollow perforated tube covered with a stainless steel filter screen that allows water to enter the well-point but keeps out sand and silt. In coarse soils, well-points are driven directly into the soil. In fine, dense soil, they are generally set in a drilled hole filled with sand, which helps keep the well-point screen from clogging with silt. French drains and collection wells can also be used to control water. Dewatering must be planned carefully because lowering the water table beneath adjacent structures may cause settlement and damage.

Water must also be kept away from the foundation walls after they are built. Groundwater is kept away by drainage or pumping systems, or the foundation is shielded by waterproofing, or both. Improper drainage has caused many needless failures of foundation walls. An ordinary foundation wall is not strong enough to act as a dam, so the groundwater must be removed. Unequal water levels on opposite sides of the wall can create destructive pressure on the wall. If the higher water level is on the outside, it can cause building elements, such as valve pits and elevator pits, to float out of the soil, despite the weight of the concrete. Perimeter drain pipe may be installed close to the foundation walls to carry excess water into a sump pit or drywell away from the structure (Fig. 4.5). Permanent pumping systems are used in some deep foundations for high-rise buildings.

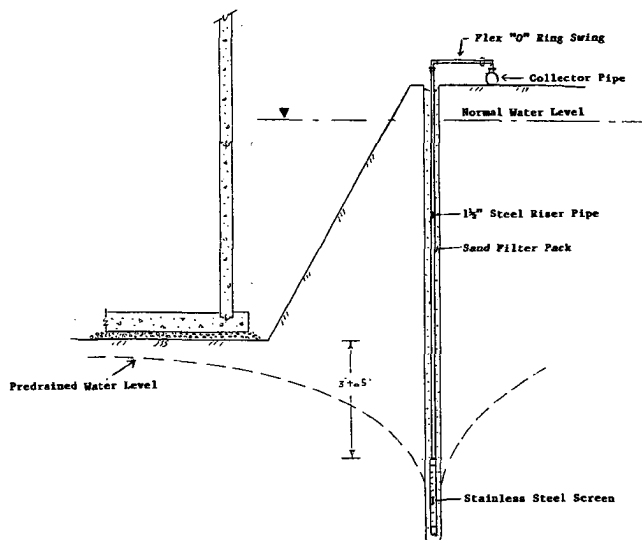


Fig. 4.4 — Typical well-point layout section. (Courtesy of MBK Dewatering Services, Inc.)

Footing Forms

Two major factors in the construction of footings are:

- The concrete must meet the specified compressive strength at the specified age.
- The footings must be accurately positioned (both vertically and horizontally) according to plans and within specified tolerances. Since footings are normally below grade, the appearance is not usually important as long as it is not at the expense of quality.

Concrete can be cast against the earth, depending on soil conditions, or in formwork (Fig. 4.6). Old or used material may be used for footing forms, provided it is sound.

If concrete is cast against the earth, care must be taken to keep soil from falling into the freshly placed concrete and to ensure that the earth does not absorb large amounts of water from the concrete. Loose soil and debris must be cleaned out of the forms before concreting. To prevent excessive loss of water from the concrete as it cures, the soil can be dampened lightly or the trench can be lined with polyethylene film.

Standard tolerances permit the footings to be oversized by 2 in. (if formed) and by 3 in. (if unformed). Reinforcement must be placed as specified, however.

Simple formwork can be used when the footings are shallow. The planks for one side of the footing are set and adjusted to line and grade and staked into position. The other side is set at the desired width and spreaders nailed down (Fig. 4.7). The nominal 2-in. thick boards are held in position by stakes about every 6 ft. If 3/4-in. thick boards or plywood are used for footing forms, the stakes should be placed every 2 ft. If the soil will not hold stakes, the forms can be braced against the sides of the excavation.

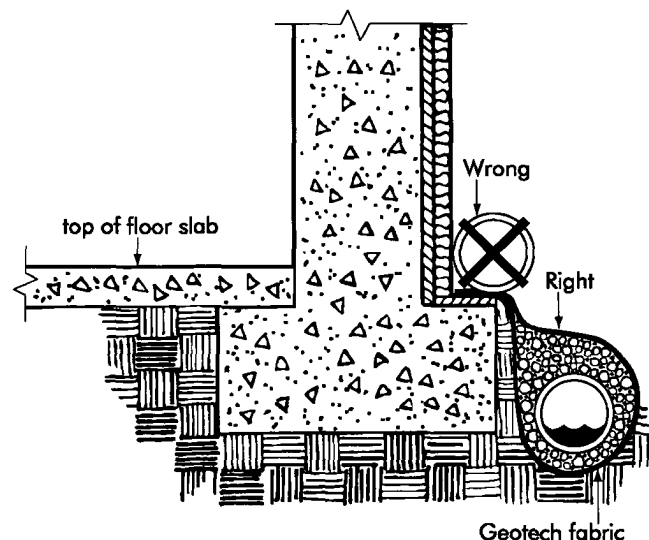


Fig. 4.5 — Drain pipe should be placed so that it is lower than the bottom of the floor.

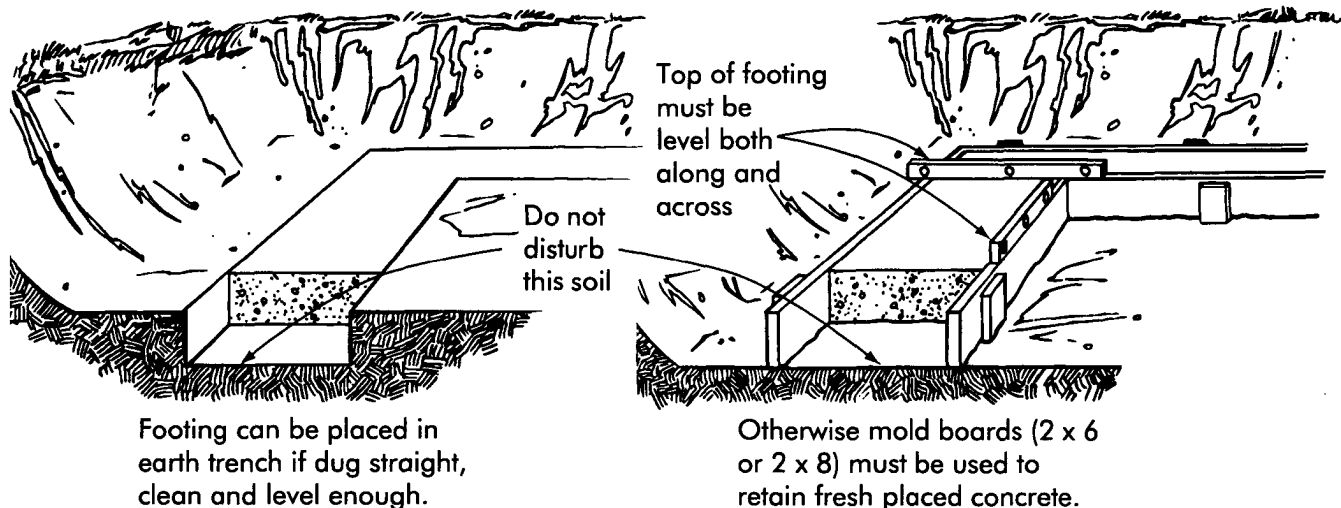


Fig. 4.6 — Footings can be built with or without forms, depending on soil conditions. A square, level bottom is important for good bearing. (Reinforcing bars are not shown for clarity.)

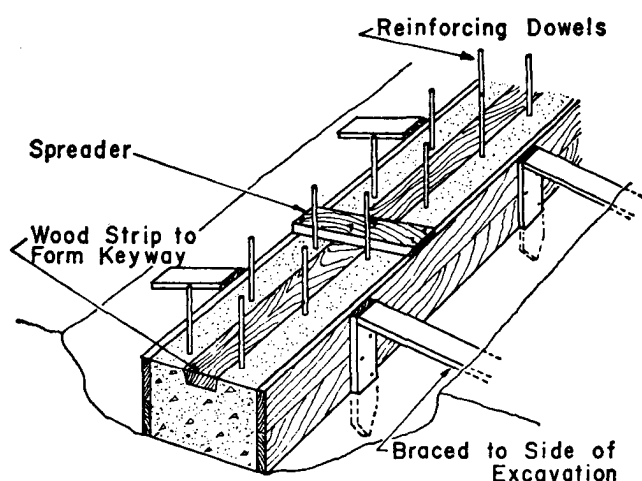


Fig. 4.7 — Low footing form for wall can be stake-braced. No ties are required, and wood spreaders across the top hold sides at correct spacing.

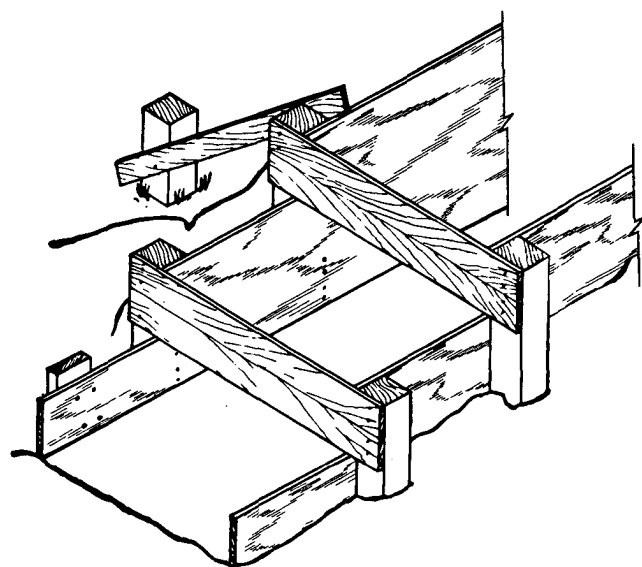


Fig. 4.8 — Stepped wall footing. Standard-size metal forms can also be used. For those, the steps should be made in increments of 2 ft.

Keyways are often built into the footing to help prevent the foundation wall from moving sideways (Fig. 4.7). Keyways can be formed with a beveled 2 x 4 that is pulled out when the concrete has reached its initial set.

For deeper wall footings and grade beams, the formwork is more elaborate and is built in much the same manner as wall forms (refer to Chapter 5). When a wall footing crosses sloping ground, the footing should be stepped longitudinally (Fig. 4.8). The spacing of the steps depends on the slope.

Simple rectangular column footing forms can be bottomless boxes (Fig. 4.9). Two opposite sides are made the exact dimension of the footing. The other two sides, perpendicular to the exact size sides, are made long enough to take care of the thickness of the form boards and the vertical cleats used for holding the sections together. Once the form is located in the correct position, it should be staked down so that it does not move during concrete placement.

Ties are used to prevent the sides from bulging under the lateral pressure from the fresh (fluid) concrete. For a shallow footing, a wood spreader nailed across the top of the form can sometimes be used instead of a metal tie. Form ties are not usually needed for the typical shallow footings used in light construction.

Sometimes, part of the load of one footing must be transferred to another, or two columns must be supported on a single footing. This type of footing is called a combined footing or strap footing (Fig. 4.3). When two columns are supported on a single footing, the form is built the same way as for a flat or stepped wall footing. If the load of one footing is to be partly transferred to another, a structural strap or beam must be built between the two footing pads.

Moisture Control

Many foundation walls serve the dual purpose of supporting a structure and enclosing a useable space. In these cases, the walls must be as watertight as possible or, at the least, dampproof.

Concrete walls can be made relatively watertight if properly designed and constructed. The concrete needs to be dense, and this means it should be placed with a minimum water content and with a compressive strength in the range of 3000 to 3500 psi. Consider air entrainment and applicable admixtures to keep permeability low. Vibrate the concrete properly. Add a waterproofing membrane for additional moisture control.

The main culprits in moisture penetration are leakage through footing-wall joints, segregation of aggregates and honeycombing, and cold joints or lift lines where successive pours have not bonded together. Careless handling of concrete or improper design of construction joints will almost always lead to a wall that is not watertight.

Seepage of water through a joint can be stopped by placing waterstops across the joint. Waterstops are strips of metal, rubber, or plastic. (Refer to Chapter 7 for information on the installation of waterstops.)

Inadequate drainage is one of the primary causes of leakage into a basement. The ground around the building should be graded so that water will drain away from the building. A drain tile system around the walls at the side of the footing, which drains to a suitable outlet or drywell away from the structure, is commonly used. Perforated plastic pipe is a common drain tile. The pipe should be placed beside the footing with the holes down so that the inlets are lower than the bottom of the floor (Fig. 4.5). The pipe should be sloped from the “rear” of the structure to the outlet or drywell at 1/8 in./ft. Sump pits and pumps can also be used to keep basements dry. Another drainage system to consider is one built into stay-in-place footing forms.

Concrete is a porous material, and drainage provisions alone will not solve all problems. Sealers and waterproofing compounds are often applied to the outside face of the wall. Waterproofing barriers include single layers of bitumastic sheeting, cold-applied systems that use multiple applications of asphaltic mastic fabric, sheet-applied elastomers, preformed rubberized bituminous sheets, bentonite-based materials, and a number of proprietary materials. Good adhesion between the clean concrete surfaces and the barrier is essential to prevent water leakage. Ironite is sometimes used to waterproof the inside of concrete walls. Some very effective proprietary drainage panels are also that can be attached to the exterior of concrete foundations.

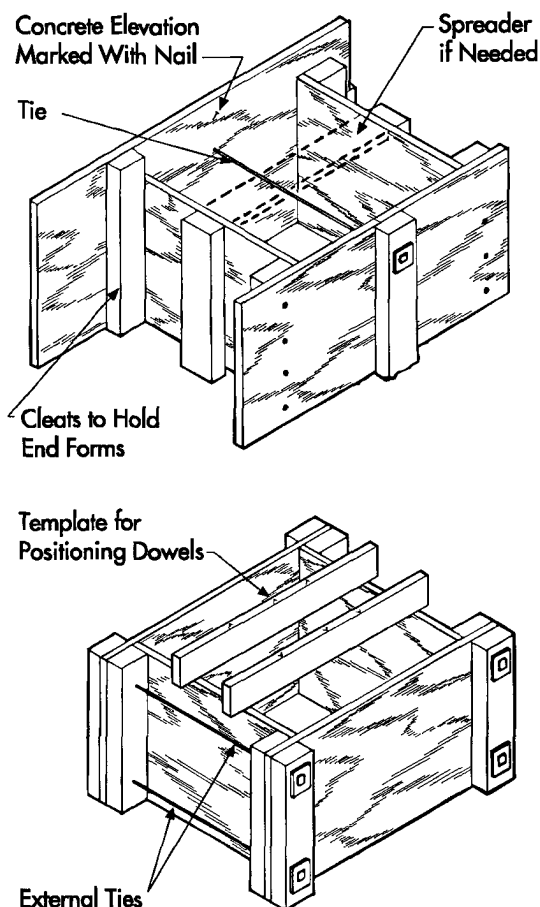


Fig. 4.9 — Two methods of forming column footings: one with internal ties and one with tie bolts outside the form.

Some of these use dimpled plastic sheets that allow any water to drain to the bottom of the wall and into the drain pipes.

Backfilling

Backfilling should be done carefully to prevent damage to insulation, waterproofing, and drainage systems. Because it takes concrete several weeks to gain its design-rated strength (its specified 28-day strength), concrete walls are not usually ready to resist earth pressures for a week or two in warm weather and longer in cold weather. Basement walls depend on the first floor framing to help brace the top edge. Backfilling should not be done before this framing is in place unless other means of bracing are provided. Interior basement walls also help brace the outer walls against backfill pressures.

If backfilling must proceed early, the wall should be braced from the inside. Water should not be allowed into an excavation prior to backfilling.

A selected material, earth, or granular fill, free of stones and debris, should be used for backfill adjacent

to foundation walls. The backfill is typically placed in 8- to 15-in. lifts depending on the material, and each lift should be compacted before the next is placed. Flowable fill is sometimes used, eliminating the need for compaction in constricted spaces.

Heavy earth-moving equipment should not operate too close to the wall. Small one-man vibratory compactors and tampers can get close to walls and do a good job. Where concrete slabs will be located on top of fill, take care that the fill is properly compacted.

All formwork materials should be removed prior to backfilling. Wood formwork will rot over time, causing settlement of the backfill and holding moisture against the concrete, which may cause unpleasant smells in the completed structure.

A word of caution: Sometimes water or sewer lines are supported on the backfill where they enter the building. Special care of the backfill both below and above these pipes is required to prevent shearing off these lines. Use a No. 57 stone or flowable fill to alleviate this problem.

Flowable fill (also sometimes called controlled low-strength material or CLSM), such as fly ash fill concrete or soil cement, is a self-compacting, cementitious material that makes an effective backfill

in place of compacted fill. Typically, flowable fill used in backfill applications has an unconfined compressive strength of 50 to 100 psi to allow for future excavation if required.

Although flowable fill generally costs more per cubic yard than most soil or granular backfill materials, its many advantages often result in lower in-place cost. The load-carrying capacity of flowable fill is typically higher than that of compacted granular material. Flowable fill does not form voids during placement and will not settle under loading. Truck mixers can deliver any amount of flowable fill to the jobsite in all kinds of weather. It can be placed by chute, conveyor, pump, or bucket. Because flowable fill is self-leveling, it needs no spreading or compacting. This speeds construction and reduces equipment (such as tampers) and labor requirements. Around pipes or electrical conduit, flowable fill can be placed with color to warn any future excavators of the utilities below.

When backfilling against foundation walls, consideration should be given to the lateral pressure exerted on the wall or pipe by flowable fill. Where lateral fluid pressure is a concern, flowable fill can be placed in layers with each layer allowed to harden prior to placing the next layer.

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, ensure 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.

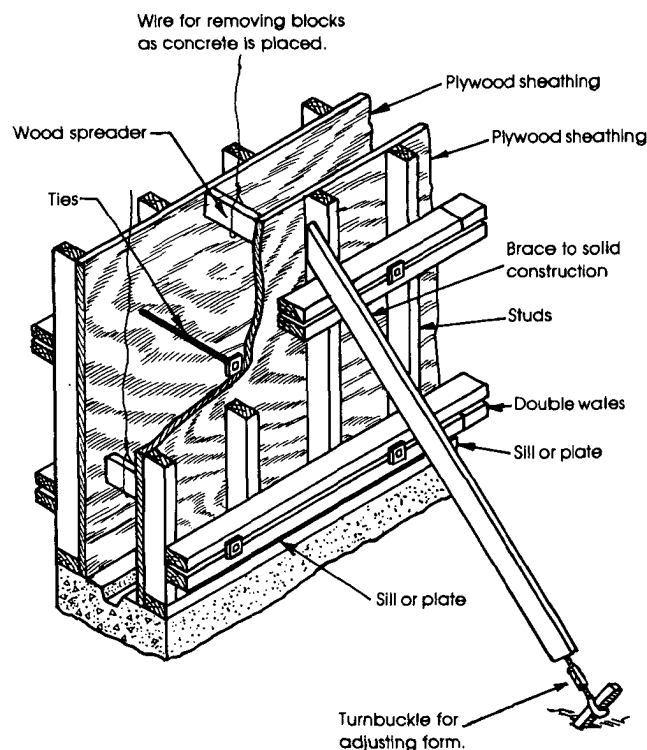


Fig. 5.1 — A typical job-built wall form. Wood spreaders are shown, but frequently the spreader device is part of the prefabricated metal tie.

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.



Documents

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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

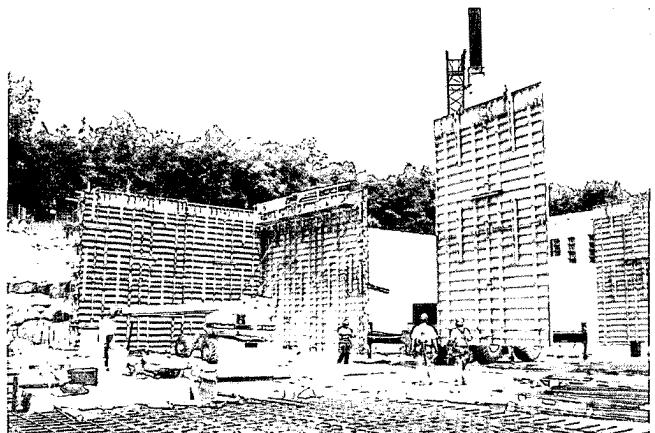


Fig. 5.2 — Gang forms being flown into position. (Photo courtesy of MEVA Forms.)

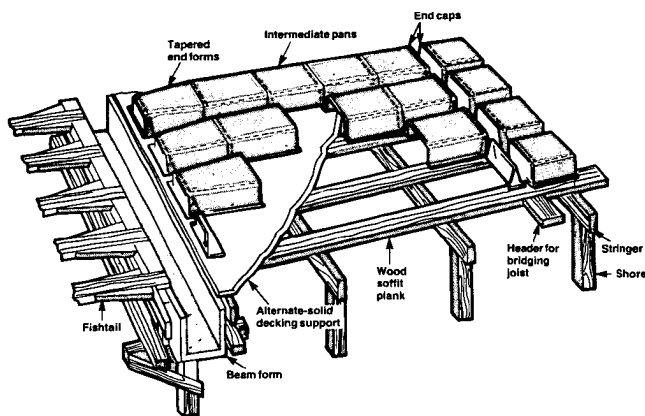


Fig. 5.3 — Nail-down pans for one-way joist construction.

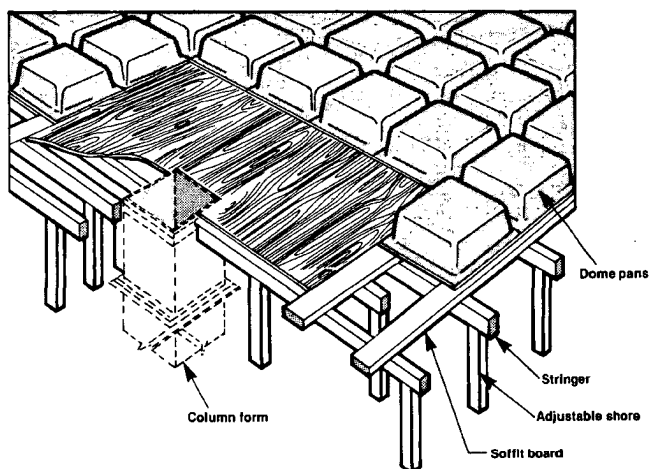


Fig. 5.4 — Dome pans for waffle slabs. Pans are omitted where solid construction is required around columns.

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.
- 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



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.)

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 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.

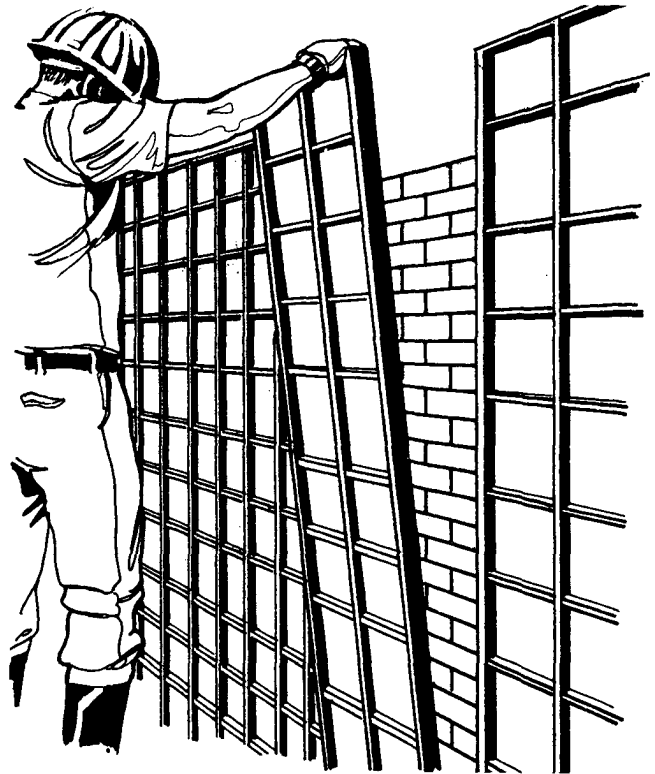


Fig. 5.6 — Cast aluminum forms with a patterned face produce a brick texture in the concrete wall.



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