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National Engineering Handbook

Chapter 12 Concrete

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645.1200 Introduction

Chapter 12, Concrete, describes the fundamentals of quality concrete and the importance of quality control and quality assurance inspection in attaining a strong and durable product. Concrete can be formed or unformed and reinforced or nonreinforced. It can be conventional or some other type such as pervious, self-consolidating, or roller-compacted concrete (described in 210–VI–NEH645.13). This chapter focuses on conventional concrete, the most common type of concrete used in conservation engineering measures. The chapter generally follows the order of NRCS National Construction Specification 31, Concrete for Major Structures, which can be found in Part 642 of the Natural Resources Conservation Service National Engineering Handbook.

Quality assurance inspectors are encouraged to consult other publications such as those from the American Concrete Institute (ACI) and Portland Cement Association (PCA). PCA Engineering Bulletin 001, Design and Control of Concrete Mixtures, is an excellent reference.

645.1201 Installation

Concrete installation is a three-stage process. The first stage, commonly referred to as pre-placement, occurs before concrete is delivered to the jobsite. It includes:

- choosing a concrete mixture
- preparing the foundation and forms
- installing reinforcing steel where applicable
- installing waterstops and joint materials where applicable
- ensuring there are adequate resources onsite to place, finish, cure, and protect the concrete

Placement is the second stage and includes:

- final check of subgrade, steel, and forms
- verifying the approved job mix is delivered
- verifying the delivered concrete mix complies with the specification
- conveying the concrete into the forms or other placement area
- consolidating the concrete
- begin finishing flatwork

The third and final stage of concrete installation is termed post-placement and includes:

- form removal
- finishing formed concrete
- final finishing of flatwork
- curing and protection
- coating where applicable

Quality control and quality assurance play a part in each stage of the installation process to ensure and verify concrete of the specified quality is attained.

(a) Materials

In its simplest form, concrete is a mixture of Portland cement, water, and aggregates. Admixtures and supplementary cementitious materials are sometimes part of the concrete mixture. Concrete work may also include forms, form release agents, curing compounds, waterstops, reinforcing steel, fiber reinforcement, expansion joint fillers, coatings, and joint sealing compounds.

Materials must be inspected to verify specification compliance. Actual testing of manufactured products, such as cementitious materials, admixtures, and steel reinforcement, is not needed if the manufacturer or supplier furnishes properly documented evidence certifying that the materials furnished meet specifications. Federal contracts require the contractor furnish material submittals that include test results that can be compared to specification requirements. Some contracts, other than Federal contracts, may only require a signed certification that the material meets specification requirements.

Aggregates make up the majority of the ingredients in a concrete mixture occupying 60 to 75 percent of the concrete volume (70% to 80% by mass). Aggregates strongly influence the concrete's fresh and hardened properties. Concrete aggregates are graded to reduce the voids between the aggregate particles and thereby limit the amount of paste needed to bond the particles together. Grading also influences the consistency (workability) of the mix. Concrete aggregates are graded in two categories, fine and coarse.

Fine aggregates consist of naturally occurring sand and/or *manufactured sand* meeting the requirements of American Society for Testing and Materials International (ASTM) C33/C33M, Standard Specification for Concrete Aggregates. Fine aggregates range in size from the Number 200 sieve size to just smaller than three-eighths of an inch. Fine aggregates are used to make mortar, which is a mixture of fine aggregates, cementitious materials, and water. When coarse aggregates are added to mortar the mixture is termed concrete.

Coarse aggregates consist of gravel or crushed stone or a combination of both. Like fine aggregate, course aggregates must meet the requirements of ASTM C33/C33M including being graded as specified. Although coarse aggregates may contain particles that are within the size range of fine aggregate, most coarse aggregate ranges upward from the Number 4 sieve size and can be as large as three and a half inches. Since smaller graded aggregates tend to segregate less than larger graded aggregates and the consistency of concrete made with smaller graded aggregates is better for placing, consolidating, and finishing, most conventional concrete is made with graded aggregates that are smaller than one and a half inches.

Concrete that contains larger maximum size aggregate requires less paste for a given concrete strength than if made with smaller aggregates. However, there is a limit on the maximum size aggregate that can be conveyed and consolidated in the structure, especially if the structure is a thin slab or narrow wall. ASTM C33/C33M designates the various coarse aggregate sizes by a size number. Size numbers 57 (1 in. *nominal maximum size*) and 67 (3/4 in. nominal maximum size) are commonly used in concrete for conservation engineering work.

Aggregates must be clean, hard, durable, and properly graded. Aggregates must also be tested for reactivity with Portland cement. Reactive aggregates can be detrimental to concrete and, in some cases, have been known to completely destroy the concrete. The most common reactive aggregates are those that contain silica that reacts with alkalies in the cement. The term used for the reaction is alkali-silica reaction (ASR), which results in expansion of the aggregate and cracking throughout the concrete. Most concrete suppliers in areas where reactive aggregates are found either avoid using the reactive aggregates or have learned how to control aggregate reactivity by adding mineral or chemical additives that stop or limit the reactivity.

Portland cement is the most common cementitious material used in concrete. It is a dry, fine powder made from silica, alumina, lime, iron oxide, and magnesia. It is termed hydraulic cement because it bonds and hardens when mixed with water. There are five basic types of Portland cement:

- Type I—commonly available and used in general construction where special properties of the other cements are not required
- Type II—used where the concrete is susceptible to moderate sulfate action or where moderate *heat of hydration* is important
- Type III—used where high early strength is needed or to accelerate strength gain in cold weather
- Type IV—used in mass concrete to control the rate of heat generation

- Type V—used in concrete susceptible to severe sulfate levels

Any of these types of cement can be blended with other materials to form blended cement. Types IA, IIA, and IIIA contain an air-entraining agent. Type IP contains fly ash or other *pozzolans*. Type IS contains blast-furnace slag cement.

If a specific type of cement is desired, it must be specified; otherwise, the least expensive cement or whatever type is readily available will be used. Typically, the local concrete supplier will use a type of cement that is generally suited for concrete work in the area.

It is common for a concrete supplier to only have one or two types of cement on hand. Type II is a common type of cement in warm climates, and often labeled Type I/II because specifications typically specify Type I or Type II and requirements for both types are met. Type III is used in colder climates and is typically only available in those areas during the colder months. Type V cement may be available in areas where there are detrimental levels of sulfates in the soil and water. These areas are generally in arid climates or coastal zones. Type IV is uncommon and may only be available by special order if large quantities are needed for a job.

Fly ash is a supplementary cementitious material that is a by-product of coal burning used for power generation. Supplementary cementious materials are just what the name implies, materials that can be supplemented for Portland cement. Some of these materials are cementitious on their own; others are classified as pozzolans which have no cementitious qualities until they are combined with Portland cement. Fly ash is classified as either Class C or Class F. Class C fly ash is cementitious on its own but may be more cementitious when combined with Portland cement. Class F fly ash is strictly pozzolanic; it will not cement unless it is combined with a cementious material such as Portland cement.

ASTM C618, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, is the industry standard for specifying fly ash. Before ASTM C618 was published in 1968, the quality of fly ash and the concrete made using fly ash was questionable. Today producers can be confident of the quality of concrete made with fly ash meeting the requirements of ASTM C618.

There are several benefits to substituting fly ash for a portion of the cement. Fly ash can improve the workability of the concrete. It may also improve the concrete's resistance to sulfates and help limit aggregate reactivity. As a pozzolan, fly ash reacts with byproducts of cement hydration to increase the strength of the concrete. This reaction occurs after the initial hydration of the cement. Since some of the cement is removed, there will be less heat generated from the chemical reaction between the cement and water. This is beneficial when installing concrete in hot weather, but not desired in cold weather concreting. Some cold weather concrete specifications do not allow fly ash to be used as a cement supplement.

Ground granulated blast-furnace slag (GGBFS) or slag cement is a hydraulic cement like Portland cement that hydrates when combined with water. Substitution rates of 25 to 70 percent are recommended when substituted for a portion of the Portland cement. Like fly ash, GGBFS sets slower and produces heat at a reduced rate compared to Type I Portland cement. As with fly ash, some cold weather concrete specifications preclude the use of GGBFS.

Silica fume is a fine particle that is, like fly ash, collected in the flue or smokestack of a coal fired power plant. It is used where a high strength or low permeability concrete is required. It is not commonly specified in NRCS work, but its use is not precluded.

Water is a key ingredient needed to hydrate the cement. Potable water or water meeting the requirements of ASTM C1602/C1602M, Standard Specification for Mixing Water Used in the Production of Hydraulic Cement, is acceptable for producing quality concrete. ASTM C94, Standard Specification for Ready-Mixed Concrete, requires that water to be used in concrete meet the requirements of ASTM C1602/C1602M.

Chemical admixtures are added to concrete mixtures for the purpose of improving the fresh or hardened concrete properties. They are available in either powder or liquid form; liquid admixtures are the most common. Admixtures should first be mixed with some of the mix water before adding them to the concrete mixture. Admixtures should never be added before the water is introduced into the mix. Table 12–1 summarizes the effects commonly used admixtures have on the concrete.

Commonly used admixtures include air-entraining admixtures (AEA), water-reducing admixtures (WRA), and set-retarding admixtures (SRA). These may be used separately or combined with another admixture. Some combinations may not be compatible when intermixed and must be added separately to the mixture. Adherence to the additive manufacturer's instructions for use is imperative. Admixture dosage is dependent on several factors including the amount of cementitious material and water in the mix, temperature of the mix, mechanism of mixing the concrete, atmospheric conditions, and effects of other admixtures in the mix. The exact dosage of each additive is learned through trial and error and adjustments are made based on experience with the specific concrete mixture and additives.

Concrete ready-mix plants typically use additives from only one manufacturer. A manufacturer's representative works with the concrete producer to set up and maintain the devices that measure and add the additives to the mix.

Air-entraining admixtures (AEA) specified by ASTM 260, Standard Specification for Air-Entraining Admixtures for Concrete, are used where, in service, concrete may be wet and frozen. Concrete without AEA generally contains 1 to 2 percent air that is entrapped in the mix. AEA is added to break up some of these macro-air bubbles into micro-air bubbles and to create more micro-air bubbles. These micro-bubbles increase the concrete's resistance to damage from freezing and thawing. Although entraining air in concrete reduces the density and strength of the concrete, the benefits of increased workability and durability generally outweigh the detriments of lower density and strength. Air entrainment also reduces the rate of bleeding which may be a detriment in hot weather because bleeding helps prevent surface drying and cracking. However, the benefits of AEA outweigh the problems associated with reduced bleeding and the problems associated with reduced bleeding can be mitigated by timely curing.

Water reducing admixtures can significantly increase the workability and pumpability of the concrete without increasing the water in the mix. They can also be used solely to reduce the amount of water in the mix which greatly improves the strength and durability of the hardened concrete. These are specified in ASTM C494, Standard Specification for Chemical Admixtures for Concrete.

High-range water reducers can greatly reduce the water demand. ASTM C494 Types F and G are high-range water reducers that can reduce the amount of water in the mixture by at least 12 percent. These are used

Table 12–1 Effects of common chemical admixtures

Common name	ASTM designation	Desired effect
Air entraining admixture (AEA)	C260	Entrain air to improve durability and workability
Water reducing admixture (WRA)	C494 Type A	Reduce water at least 5%
Retarding admixture	C494 Type B	Retard setting time
Accelerating admixture	C494 Type C	Accelerate setting and early strength development
Water reducer and retarder	C494 Type D	Reduce water at least 5% and retard set
Water reducer and accelerator	C494 Type E	Reduce water at least 5% and accelerate set
High-range water reducer	C494 Type F	Reduce water at least 12%
High-range water reducer and retarder	C494 Type G	Reduce water at least 12% and retard set
Superplasticizer	C1017/1017M Type I	Increase flowability
Superplasticizer and retarder	C1017/1017M Type II	Increase flowability; retard set

to make high strength concrete. The same high-range water reducers are specified in ASTM C1017/C1017M, Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete. In ASTM C1017/C1017M the water reducers are designated Type I and II and are often called superplasticizers. These superplasticizers are used in the precast concrete industry where precast concrete members contain large amounts of congested steel reinforcement making it necessary to use concrete that can flow through and around the steel with minimum segregation.

The use of ASTM C1017/1017M superplasticizers has led to the development of what is termed self-consolidating concrete (SCC) that can be placed without vibrating and with minimal segregation. For conservation engineering concrete work, admixtures meeting the requirements of ASTM C1017/1017M Type I and II may be substituted for the more commonly specified ASTM C494 Type F or G (respectively).

Retarding admixtures retard the time of set to give the contractor more time to place, consolidate, and finish the concrete before it becomes too stiff. Retarding admixtures are commonly used in hot weather concreting; they may double the initial set time of the concrete mix. Conversely, accelerating admixtures can accelerate the set time and are generally used in cold weather concreting.

Calcium chloride is an accelerating admixture, but not recommended for steel reinforced concrete since the potential for corrosion of the steel greatly increases. Calcium chloride should not be used at a rate of more than 2 percent, by mass, of the cementing material. Calcium chloride may cause an increased shrinkage and darkening of the concrete. Construction Specification 31 precludes the use of calcium chloride in steel reinforced concrete.

Accelerating admixtures meeting the requirements of ASTM C494 Type C will accelerate the set of concrete without the increased potential for steel corrosion. Use of extra cement or Type III cement may have an equivalent effect to using an accelerating admixture.

Chemical additives have a limited time of effect and should be added at the site if there is a long travel time between the batch plant and the construction site. Water reducing admixtures are typically used to make the concrete more workable without increasing the water content, but the concrete will lose workability faster than concrete which gets its workability by adding more water. For this reason, adding water reducers at the site is common. Entrained air will tend to dissipate until the concrete makes its initial set with most of the dissipation happening in the rotating concrete truck drum. This is especially true in hot weather when it is common for AEA to be added to the mix at the jobsite.

Additives included in the mixture at the batch plant that dissipate during transport can be successfully added again on the jobsite only if they are mixed with a few gallons of water. But, the amount of total water added to the mix must never exceed the maximum amount of water called for in the job mix design.

Curing compounds are specified in ASTM C309, Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete. There are three types and two classes of curing compounds. Type 1 is clear or translucent and Type 2 is white. Type 1–D is a Type 1 compound with a *fugitive dye* which fades several hours after it is applied. Any of these types can be classified as Class A or B. Class A is wax based and Class B is resin based. ASTM C309 curing compounds should be removed from the surface by sand blasting if the surface is to be coated, painted, or bonded to other concrete.

ASTM C1315, Standard Specification for Liquid Membrane-Forming Compounds Having Special Properties for Curing and Sealing Concrete, covers compounds that cure and seal. These membranes have special properties, such as, alkali resistance, acid resistance, adhesion-promoting qualities, and resistance to degradation by UV light. As with ASTM C309 compounds, ASTM C1315 compounds include a Type I which is clear or translucent and a Type II which is white. These are designated by Roman numerals whereas the ASTM C309 types are designated with Arabic numerals. ASTM C1315 comes in three classes:

- Class A is essentially non-yellowing
- Class B is moderately yellowing
- Class C is not restricted when it comes to yellowing.

The adhesion-promoting qualities assure that flooring adhesives, such as those used for ceramic tile, will bond to the surface without having to remove the curing and sealing compound. If bond is absolutely necessary it is prudent to test the amount of bond according to ASTM C1583/C1583M, Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method). Otherwise, the compound should be removed before placing fresh concrete against the surface whenever bonding is required.

Preformed expansion joint filler is used in expansion joints as a compressible material that is used to hold the joint open to a specific width. ASTM D1752, Standard Specification for Preformed Sponge Rubber Cork and Recycled PVC Expansion Joint Fillers for Concrete Paving and Structural Construction, specifies:

- Type I, sponge rubber
- Type II, cork
- Type III, self-expanding cork
- Type IV, recycled PVC

ASTM D994/D994M, Standard Specification for Preformed Expansion Joint Filler for Concrete (Bituminous Type), and ASTM D1751, Standard Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types), cover bituminous type expansion joint filler materials.

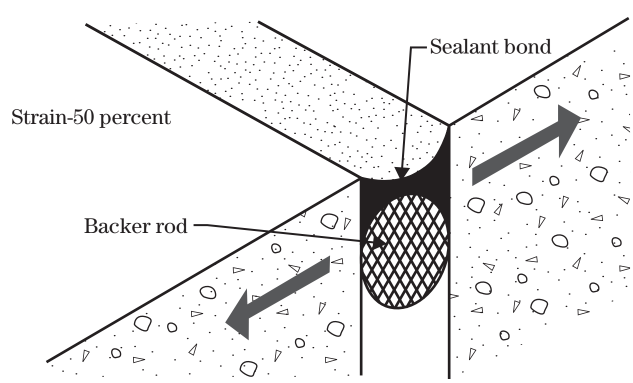
The quality and price of expansion joint fillers varies widely. Any nonabsorbent material can be used to form a joint, but the material must be compressible if the concrete is going to expand any time after it is poured. The higher quality materials are high-density foam rubber made from virgin rubber meeting the requirements of ASTM D1752, Type I. These materials are compressible and will expand back to their original shape.

Sealing compounds for joints are installed at the top of horizontal joints and at the exposed surface of vertical joints. Sealing compounds are made from a wide variety of materials and material combinations including rubber, bitumins, and polymers. These materials are combined with other materials to produce sealants with various physical properties. The designer should specify a material that will expand and contract with the joint. If little or no joint movement is expected, the sealant simply needs to bond well and seal the joint; a bituminus sealer is often used when little or no joint movement is anticipated. Elastomeric sealing compounds are generally specified if substantial joint movement is expected.

Sealing compounds that must expand and contract generally require a backer rod to be placed in the joint so that the bottom of the sealant is concave. The top of the sealing compound is then tooled to the same concave shape as the backer rod so that it is thin in the middle but has substantial bonding surface against the sides of the joint opening. Figure 12–1 illustrates proper joint sealer installation.

Joint sealers are specified based on the anticipated amount of joint movement and on the environment to which they will be exposed. Product data sheets should be referenced or the manufacturer contacted to confirm the sealers compatibility with chemicals that are present. It is important that the specified joint sealer is provided and the manufacturer's specified shelf life has not expired at the time of installation. The backer rod and any products used to prepare the bonding surface must comply with the sealing compound manufacturer's recommendations.

Figure 12–1 Proper joint sealer installation.



Waterstops are embedded in the concrete at joints to stop water from flowing through the joint. They can be metallic (galvanized or copper) or non-metallic. Non-metallic waterstops are fabricated of PVC, copolymer, natural rubber, or synthetic rubber. Nonmetallic water-stops are more common in conservation engineering work than metal waterstops and come in a variety of shapes and sizes. Waterstops that are installed at an expansion joint have a bulb or fold that is centered at the joint to allow movement without tearing the water-stop. The size of the bulb or fold must meet specifications to allow for the planned joint movement. Waterstop splices are made by chemical or heat fusion. Figure 12–2 shows some waterstops.

Dowels are smooth round bars used to transfer shear loads from one slab section to the next. Dowels transfer shear loads at the joint while allowing the joint to open and close horizontally. They are generally epoxy coated to guard against corrosion because, unlike fully embedded reinforcing steel, the portion of the dowel at the expansion joint may be exposed to potential corrosive elements.

Generally, dowels are accompanied by a plastic cap that is placed over one end of the dowel (fig. 12–3). The plastic cap is manufactured so that, when slid onto the bar, there is a space between the end of the bar and the end of the cap to allow the bar to slide further into the concrete when the concrete expands. The inspector should verify that the cap is the correct cap for the dowel by verifying it fits snuggly onto the dowel and that there is indeed the desired space from the end of the dowel to the end of the cap when the cap is firmly pressed (by hand) onto the dowel.

Metal plates and appurtenances may include brackets to attach posts or other items, trash racks, valves, and other appurtenances for controlling flow in hydraulic structures. Metal plates may also be embedded in the concrete at joints to resist shear loads at the joint. The specifications normally specify metal type and coating if required.

Steel reinforcement is made from structural grade steel and comes in several grades. The three primary grades are Grade 40 (40,000 lb/in^2 minimum yield strength), Grade 60 (60,000 lb/in^2 minimum yield strength), and Grade 75 (75,000 lb/in^2 minimum yield strength). Typically, NRCS specifies Grades 60 or 75 for concrete reinforcement used in project work.

Each individual steel bar is manufactured with a series of individual markings as seen in figure 12–4. The top letter or symbol in these markings identifies the producing mill. The next marking is the bar size. The third marking symbol designates the type of reinforcing bar, usually either S for carbon-steel, W for low-alloy steel, or N for new billet. If there is a fourth marking it designates the grade; the grade corresponds to the

Figure 12–2 PVC waterstops

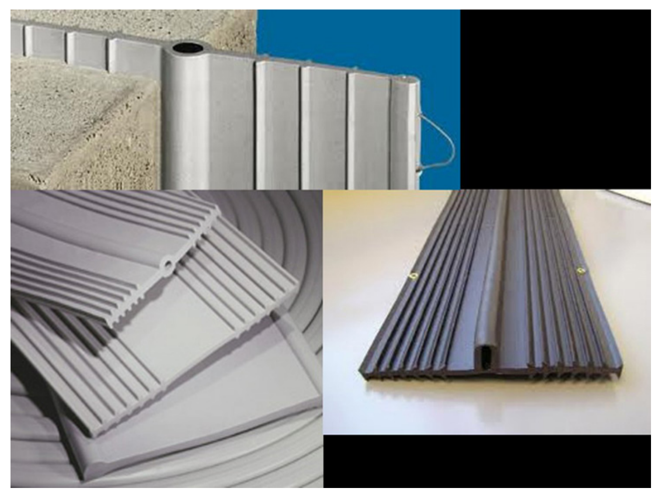
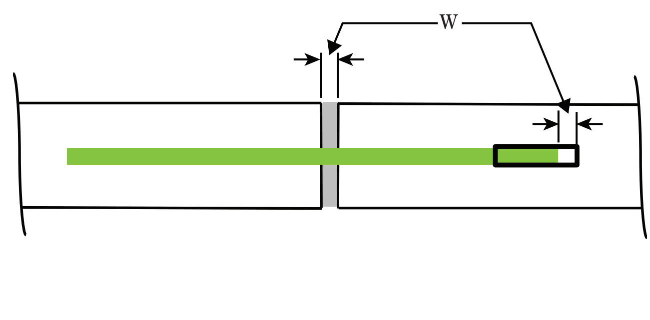


Figure 12–3 Dowel with plastic cap



yield strength of the steel. Grade 60 may be designated by a 60 with a corresponding yield strength of 60,000 pounds per square inch or its metric equivalent 420 megapascals which may be indicated by the numeral 4. Likewise, Grade 75 may be designated by the metric Grade 520 or indicated by the numeral 5. If no grade number is shown, the grade will be indicated by one or two lines running the length of the bar. One line indicates Grade 60, two lines indicate Grade 75, and no lines indicates Grade 40. The lines are not to be confused with the two ribs (main ribs) that run down the side of the rebar.

Bar sizes of reinforcing steel are numbered from 2 through 18 although No 2 bars are not common. The number designates the approximate diameter in one-eighth inch increments. For example, No. 7 has a seven-eighths inch diameter. This designation is accurate for bars 3 through 9. For sizes larger than No. 9, the multiple is slightly more than an eighth of an inch.

Weights and nominal dimensions for standard bar sizes are shown in table 12–2.

Bars with metric designations are generally, but not always, manufactured overseas. Metric size designations, like the English designations, are nominal numbers that vary slightly from the actual size marked on the bar.

Bars with metric designations that are manufactured in the United States are generally manufactured to the same dimensions as those with English unit designations. They have metric designations because of a Federal government requirement for manufacturers to convert to metric measurements; but rather than retooling their dies to metric, they simply designated the bars with metric designations corresponding as closely as possible to their dimensions. This type of metric designation is termed soft metric.

Galvanized or epoxy-coated steel bars for concrete reinforcement are not commonly used in NRCS work. They are commonly used in corrosive environments, such as parking garages in colder climates, highway bridges and roads, and coastal environments. They can have their effectiveness compromised by holidays or breaks in the coating. If coated bars are cut or the coating is damaged, a repair to keep the coating intact is necessary.

Welded wire fabric (WWF) is available in rolls for light gauges and in large sheets for heavier gauges. As with any steel reinforcement it is important to place the steel at the specified location within allowable tolerances. This is difficult to do with light gauge fabric

Figure 12–4 Deformed steel reinforcement bars

Identification marks ASTM standing bars

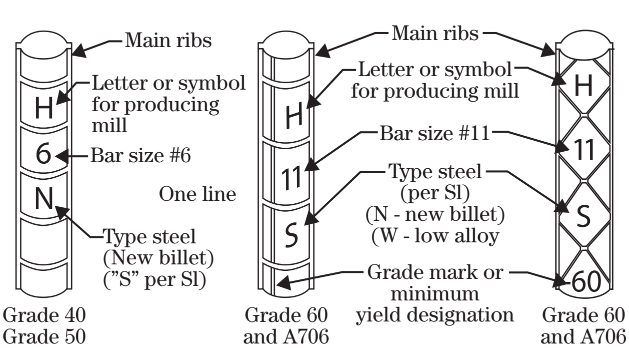


Table 12–2 Weights and nominal dimensions of standard bar sizes

Size	Weight (lb)	Diameter (in)	Cross sectional area (in^2)
3	0.376	0.375	0.11
4	0.668	0.500	0.20
5	1.043	0.625	0.31
6	1.502	0.750	0.44
7	2.044	0.875	0.60
8	2.670	1.000	0.79
9	3.400	1.128	1.00
10	4.303	1.270	1.27
11	5.313	1.410	1.56
14	7.650	1.693	2.25
18	13.60	2.257	4.00

that comes in a roll. The fabric that comes in sheets is preferred over that in a roll.

WWF is manufactured in square and rectangular patterns and may have one-way reinforcement of heavy-gauge wires closely spaced in a lengthwise direction or two-way reinforcement of heavy-gauge wires spaced equally in each direction. WWF generally comes in 6, 8, or 10 gauge wire. A 6 by 6 inch grid pattern is common.

WWF is designated by letters that denote the type of wire and numbers that relate to the cross-sectional area of each wire. For example, W 0.5 denotes plain wire with a cross-sectional area of 0.005 square inches. MW 5 is a smooth wire measured in metric units with a nominal cross-sectional area of 5 square millimeters. D1 is a deformed bar with a cross-sectional area of 0.010 square inches. MD 25 is a metric deformed bar with a cross-sectional area of 25 square millimeters.

Fiber reinforcement can be steel, fiberglass, synthetic, or natural fibers that are mixed into and well distributed throughout the concrete.

Steel fibers may be a viable option for reinforcement of concrete. Generally, an amount of steel fibers weighing twice the weight of steel reinforcing bars is required to develop the equivalent strength of steel bars. Since steel fibers cost more per pound than reinforcing bars and significantly more pounds are used, they are normally not an economical alternative to reinforcing bars. They can be useful for small quantities of concrete in hard to reach areas or areas that would otherwise be congested with reinforcement.

Synthetic fibers are commonly incorporated into concrete to slightly reduce the permeability, improve abrasion resistance, and help to reduce *plastic shrinkage cracking*. The most common synthetic fiber reinforcement is polypropylene, which is typically used at a rate of about 0.1 percent by volume or 1.5 pounds per cubic yard of concrete. Synthetic fibers are not a substitute for structural or temperature and shrinkage steel reinforcement.

Glass fibers are available but not commonly used in the concrete industry because of the adverse reaction between the silica in the glass and the alkalies in cement. Natural fibers have also been used to reinforce concrete but are not common.

Surface sealing compounds are sometimes used to reduce concrete permeability. There are two general types of sealing compounds, film forming and penetrating. Manufacturer's recommendations for application and use are generally specified.

Film forming sealing compounds such as epoxies and urethanes are used to reduce penetration of liquids, such as deicing solutions and chemicals. Dusting of the concrete is also reduced and the protected film provides for easy cleanup of oils and grease. They are frequently specified for secondary containment of chemicals. Surface preparation is critical to the success of any film-forming sealer.

Penetrating sealers can be made by combining one part boiled linseed oil with one part mineral spirits. Commercial penetrating sealers contain silane and siloxane. The silane and siloxane sealers may allow vapor and water to bleed from the concrete, making them more appropriate for newer concrete. They also are less apt to be damaged by abrasion or ultraviolet light than film forming sealing compounds.

(b) Concrete mix design

Concrete mix design refers to selecting and proportioning of materials used to make the concrete mixture. The basic materials are Portland cement, aggregates, and water. Other materials such as fly ash and admixtures may also be incorporated into the mixture.

Construction Specification 31 lists two methods for concrete mix design. Method 1 requires the contractor submit a mix design. Method 2 states that the engineer is responsible for the mix design. If Method 1 is specified, the contractor will submit the mix design for concurrence from the engineer. If Method 2 is specified, the mix design will be specified; the mix design may be revised by the engineer if necessary to meet the design intent. Regardless of the specified mix design method, the contractor must submit data showing that the materials (ingredients) that will be used to make the concrete mixture are of the specified character and quality. After the job mix has been accepted it must not change without the approval of the engineer. Any revisions to the job mix, including the source of materials, must be submitted to the engineer and follow the same submittal and acceptance process as that for the initial job mix.

Method 1 is more commonly used for conservation engineering work. When Construction Specification 31 Method 1 is specified there are several items that must be included in the specification details. These are:

- class of concrete
- type of cement
- water-cement ratio if other than 0.50
- air content if other than specified in Construction Specification 31
- types of admixtures
- nominal maximum size of coarse aggregate
- requirement for fly ash or ground blast-furnace slag if applicable

If Method 2 is specified, the mix proportions must also be provided in the construction details.

The **class of concrete** is designated by the specified 28-day compressive strength. The concrete industry tests for concrete compressive strength 28-days after the concrete mixture is produced. If the 28-day strength is specified to be 4,000 pounds per square inch, the concrete is designated Class 4000.

The designer will specify the **type of cement** that must be used depending on the type of structure and the environment where it will be installed. For example, if the concrete will be exposed to sulfates, a Type II or V sulfate resistant cement is specified. If the concrete will be subjected to severe sulfate attack, Type V cement should be specified; in this case it would be unacceptable to use another type unless test results indicate otherwise. Since Type V cement is often not available, adding fly ash to a concrete made with Type II cement may provide the needed sulfate resistance. The ability for fly ash to improve sulfate resistance can be verified by a laboratory test.

Water-cement ratio (w/c) is the ratio of the mass of free water (water that mixes with the cement to form the paste) to the mass of cement in the concrete mix. High w/c contributes to poor concrete strength and poor durability. Concrete with a low w/c may be too stiff to place, consolidate, and finish as specified. Selecting the proper w/c is key to producing a concrete mix that is workable yet strong and durable.

Since limiting the w/c is critical to producing quality concrete, Construction Specification 31 specifies a maximum value of 0.50. For most conservation engineering measures, adequate concrete strength and durability can be attained with a w/c of 0.50, and concrete with a w/c of 0.50 generally has good workability. Some conservation engineering measures (e.g. some agricultural waste storage facilities) require limits on concrete cracking and permeability. The maximum w/c for concrete used to construct these structures is typically specified to be less than 0.5 (e.g. 0.45 or 0.40).

The inspector must understand how to compute the w/c to verify that the specified maximum has not been exceeded. The w/c is computed by dividing the free water in the mix by the cement in the mix. Free water is all of the water in the mix minus that absorbed into the aggregates. Table 12–3 and equation 12–1 show how to compute the w/c.

The concrete mix design must list all of the ingredients in the mix along with the *absorption* of the aggregates. Aggregate absorption is shown as a percentage of the dry aggregate weight. For example, 100 pounds of fine aggregate with an absorption of 5 percent can absorb 5 pounds of water ($100 \times 0.05 = 5$). When this fine aggregate absorbs all of the water it can absorb it will weigh 105 pounds. This weight is termed saturated surface-dry weight (SSD), meaning that it is completely saturated but the surface of the particles are dry. If the surface of the particles are not dry there will be additional water clinging to the aggregate particles. This additional water is termed free water meaning it is free to contribute to the paste.

An **air-entraining agent (AEA**) is added to concrete primarily to improve resistance to freeze-thaw damage. Air is either entrapped or entrained in the paste. Concrete made with relatively small graded aggregates contains more paste than concrete made with larger graded aggregates. Thus, concrete made with a one inch or less maximum size aggregate is specified to have an air content ranging from five to seven percent whereas concrete made with larger aggregates (maximum size over 1 in) is specified to have a lesser amount of air ranging from four to six percent.

Table 12–3 Typical concrete mix ingredients showing saturated surface-dry and oven-dry weights

Ingredient	**(a)** **Weight** **Mix design** **(lb)**	**(b)** **Absorption** **Determined in lab** **(%)**	**(c)** **SSD Wt.** $\frac{a}{\left(1+\frac{b}{100}\right)}$ **(lb)**	**(d)** **Moisture** **Field measurement** **(%)**	**(e)** **Oven dry weight** $\frac{a}{\left(1+\frac{d}{100}\right)}$ **(lb)**	**(f)** **Free water** c – e **(lb)**
Cement	564	-	-	-	-	-
Water	223	-	-	-	-	223
Fine agg.	1,125	1.0	1,114	6.2	1,059	55
Coarse agg.	2,079	4.2	1,995	4.4	1,991	4
Total free water						282

$$w/c = 282 \div 564 = 0.5 \qquad \text{(eq. 12–1)}$$

Adding an AEA to the mix will reduce the compressive strength. This can be compensated for by adding more cement or reducing the w/c. Since air bubbles act like tiny ball bearings to make the concrete more workable, adding the AEA may allow the w/c to be reduced without having an adverse effect on workability. When designing a mix in the laboratory, the mix should contain an air content within 0.5 percent of the upper range of allowable air content so that mix strength tests will represent the strength of the mix with near maximum air content.

In addition to AEA, **other types of admixtures** may be needed. It is common to add a water-reducing admixture (WRA) to either improve workability without adding water or to reduce the water content to improve strength. It is generally acceptable to add a WRA to the mix even though it may not have been included in the approved job mix. If a WRA is included in the approved job mix, it should be used for all of the concrete made with that mix.

ASTM C495 Type F is a high range water reducer; it is the same as ASTM C1017/C1017M Type I which is commonly referred to as a superplasticizer. ASTM C495 Type G and ASTM C1017/C1017M Type II are a high-range water reducer and a superplasticizer, respectively, which contain a set-retarder.

The engineer has to approve the inclusion of any admixture that was not included in the approved job mix. Likewise, the engineer must approve leaving out any admixture that was included in the approved job mix.

The *nominal maximum size* of the course aggregate should be specified. The size of aggregate that can be placed, consolidated, and finished is contingent on the depth of the slab or thickness of the wall being constructed and the clear spacing through which the concrete will have to flow. ACI recommends the nominal maximum size aggregate be smaller than one-fifth the narrowest dimension of a vertical concrete member, three-quarters the clear spacing between reinforcing bars and between the reinforcing bars and the forms, and one-third the depth of a slab.

Fly ash or ground blast-furnace slag may be specified; otherwise they are allowed to be used at the concrete supplier's discretion. These supplementary cementitious materials may help control the initial heat of hydration or impart some favorable quality on the fresh or hardened concrete. Construction Specification 31 allows fly ash to replace up to 25 percent (by weight) of the Portland cement and allows ground granulated blast-furnace slag (GGBFS) to replace Portland cement at a rate of 25 to 70 percent by weight. More GGBFS is allowed because it has cementitious properties on its own, unlike pozzolans such as Class F fly ash which only become cementitious when combined with Portland cement.

When method 1 is specified, the contractor must show that the proposed job mix can meet the compressive strength **job mix criteria**. The contractor will submit records from previous batch records or laboratory trial mixtures showing strength history of the proposed job mix. The engineer will analyze these records to verify that the proposed mix has a high probability of meeting the specified strength.

When Method 2 is specified, the mix proportions are provided in the specified details. The contractor will submit evidence that the concrete ingredients meet specification requirements and provide strength history of mixtures made by the concrete supplier that are proportioned similar to the specified mix. If the specified mix is similar to one of the *off-the-shelf* mixes sold by the concrete supplier, the engineer may choose to use the off-the-shelf mix in lieu of the specified mix.

Regardless of the specified method of mix design, the engineer must be confident that the approved job mix can consistently meet strength requirements. Any testing that is done on a batch of concrete made to evaluate the proposed mix must be done far enough in advance of the first concrete placement in order to attain the results of 28-day compressive strength tests.

(c) Inspecting and testing

Fresh concrete is tested to verify that the specified requirements for consistency, air content, and temperature at time of placement are met. It is then tested after it hardens to verify that it meets the strength requirement.

Concrete testing is an important part of concrete inspection, but it is only a part of quality control and quality assurance inspection. It is important that the inspector not become focused on testing to the point that problems with the concrete installation go unnoticed. Having a qualified testing firm or an assistant perform the sampling and testing of fresh concrete may be necessary to give the construction inspector the opportunity to review batch or delivery tickets and observe conveying, placing, and consolidating of the concrete mix.

NEH645.1202, Sampling and testing, describes proper sampling and testing for verifying specification compliance. There is also a discussion on testing in Section (i) Placing concrete.

(d) Handling and measurement of materials

Proper handling and measurement of materials is necessary for batching consistently good concrete. Most concrete used for conservation engineering work is supplied by a ready-mix concrete supplier. For concrete supplied by a ready-mix supplier, it will likely not be necessary to inspect the handling and measurement of materials unless *mix uniformity* problems are noted.

Significant batch-to-batch variations in consistency, air content, and unit weight may be caused by inadequate mixing, but these variations are more likely to be caused by improper, inconsistent, or incorrect handling and measurement of the materials being batched. Investigating the cause of uniformity problems may require that the inspector visit the plant to observe the process. If so, the inspector must observe stockpiling and removal of materials from stockpiles, adjusting *add-water* quantities to take into account free water in the aggregates, and batching and mixing of the materials. It is prudent to call on the responsible engineer to assist with plant inspections.

Care in handling of aggregates is especially important to prevent segregation. Coarse aggregates tend to segregate more than fine aggregates, but both will segregate. Fine aggregates containing moisture within the *bulking moisture* range tend to clump together; this helps limit segregation. Coarse aggregate moisture has little or no effect on its tendency to segregate.

When moving and stockpiling aggregates, especially coarse materials, care should be taken to limit the drop height and pile height to no more than five feet. Aggregates that are dropped or allowed to free fall five feet or more tend to segregate. If aggregates are deposited onto a pile so that they roll down the side of the pile, segregation will occur with the larger particles accumulating at the bottom of the pile. Removing materials from the bottom of a pile, especially a tall pile, will result in a steep face with materials falling and rolling to the bottom of the pile; this causes segregation.

Cementitious materials such as Portland cement, fly ash, and slag must remain dry until introduced into the mix. These are pneumatically blown into the silo or hopper from a cement transport truck where they are stored until deposited into the mix. These very fine materials tend to pack and clump together and may not uniformly flow from the storage container without vibrating or blowing air though the material in the container. Modern cement silos include equipment that will keep the material flowing.

For small batches and onsite batching, cement can be purchased in 94 pound sacks. Ninety-four pounds of bulk cement occupies a volume of approximately 1 cubic foot. This measure was historically used to batch concrete by volume. Today, concrete suppliers batch concrete by weight because it is more accurate than volumetric batching.

Mixing water is either metered by volume or batched by weight. Since aggregates should be maintained above the saturated surface-dry condition (SSD), there should be some free-water on the aggregates. The plant operator must understand and take into account aggregate moisture so that the amount of water that is added to the mix does not exceed that called for by the job mix. Many modern plants have a moisture probe fixed in the fine aggregate stream to measure aggregate moisture as the fine aggregate is flowing to the weigh hopper. Computer controls can adjust for aggregate moisture in real time so that the amount of add-water is constantly adjusted. Other less sophisticated plants employ experienced employees who can test aggregate moisture and judge the consistency of the mix to control the amount of water in the mix to within an acceptable range. With either method, it is important to know the exact amount of water that will contribute to the paste so as not to exceed the maximum w/c called for by the job mix.

The sequence in which the ingredients are introduced into the mixer (charging the mixer) is important. The sequence must generally remain the same from batch to batch. It is recommended that, for drum mixers, most of the water and all of the coarse aggregate are first put in the mixing drum followed by the remaining ingredients. When heated water is used, the cementitious materials should not be added until the aggregate and water have intermingled. Adding the water and aggregate first allows the water to cool as it warms the aggregate. This will help to avoid rapid stiffening of the cement that might occur if the water were too hot.

Chemical admixtures are added into the mix with the add-water. Most concrete plants use admixtures from only one manufacturer and the chemical admixture manufacturer understands the importance of proper dosing and metering of admixtures. Therefore, the metering device that is used to measure the admixture may be provided, calibrated, and maintained by the admixture manufacturer.

Retarding and water reducing admixtures must be added at the same time in the charging sequence for each batch so that the mix set times are consistent from batch to batch. These admixtures must be added within one minute of introducing the water to the cement and prior to the start of the last three fourths of the mixing cycle.

When two are more admixtures are added to the mix, they must be added separately with several drum rotations between the adding of each admixture to avoid interaction that might adversely affect the concrete.

Figure 12–5 Rotating-drum stationary mixer (*courtesy of the Portland Cement Association*)

The inspector's responsibilities related to handling and measurement of material include verifying:

- mix is consistently uniform
- problems with mix uniformity are investigated and corrected
- problems with mix uniformity are documented

For on-site batching and mixing or if the batch plant is inspected:

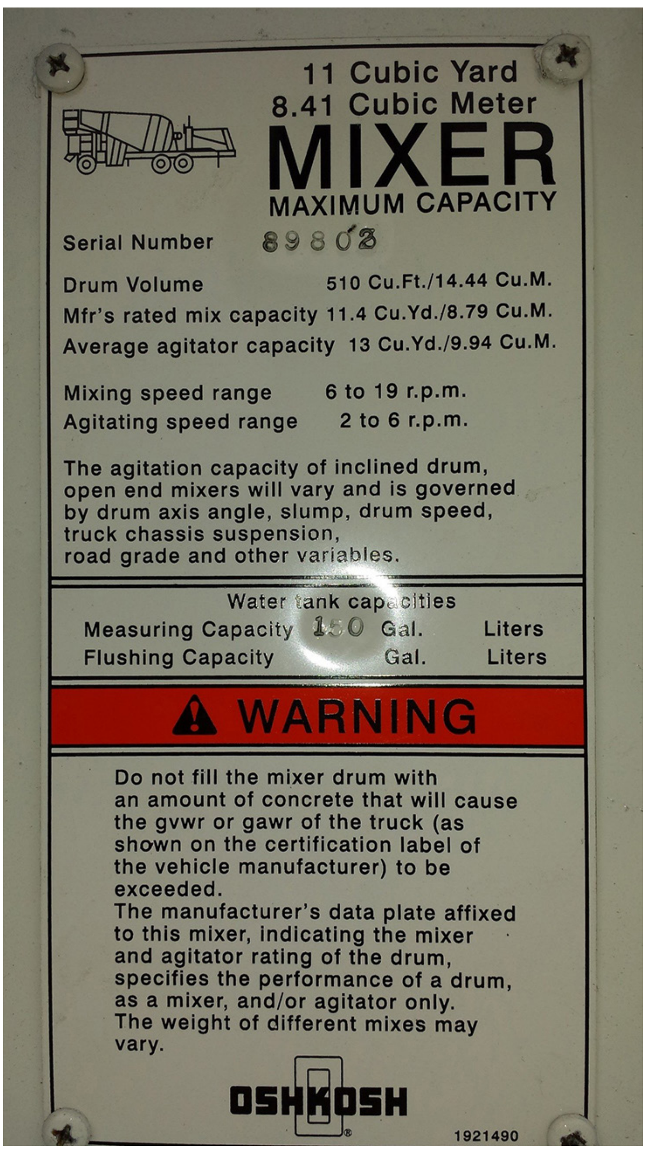
- materials are handled properly
- materials are accurately measured

Figure 12–6 Rotating-drum concrete truck (*courtesy of the Portland Cement Association*)

Figure 12–7 Mobile concrete truck mixer (*courtesy of the Portland Cement Association*)

- sequence in which materials are batched is consistent
- add water is adjusted to account for aggregate free-water
- if applicable, cementious materials are not added until hot water has had a chance to cool

Figure 12–8 Rating plate on a rotating-drum truck mixer



- cementitious materials are kept dry until introduced into the mix
- cementitious materials flow freely from the silo

(e) Mixers and mixing

Concrete mixers employ either a rotating drum or an auger to mix all of the ingredients. Rotating-drum mixers (figs. 12–5 and 12–6) are used for making ready-mixed concrete commonly used for most concrete work. Both augers and rotating drum mixers are used in portable batch plants which can be set up at the construction site. Auger-type mixers are used in mobile concrete truck mixers (fig. 12–7) that are designed to batch and mix concrete onsite.

Mixers are rated for capacity. Auger-type mixer capacity is expressed in volume that can be produced in a specific time period. This is generally a manufacturer set production rate that cannot be changed. Rotating-drum mixer capacity is expressed in drum volume; a rating plate should be affixed to the mixer showing the drum volume (fig. 12–8). The typical truck mixer is a 9 to 11 cubic yard unit. The drums are designed with a rated maximum capacity of 63 percent of the gross drum volume as a mixer and 80 percent of the drum volume as an agitator. The inspector should verify the rated maximum capacity is not exceeded as this could result in the concrete not being uniformly and thoroughly mixed.

Concrete ingredients must be uniformly and thoroughly mixed so that all aggregates are coated with cement paste. To accomplish this, the mixer must be in good condition, the batch size must not exceed the rated capacity of a drum mixer, and the mixing time and drum speed must be adequate to provide the needed mixing effort. For auger-type mixers, the auger speed and auger length control the mixing action and time of mixing.

There are three methods of producing a concrete mix: ready-mixed concrete, volumetric batching and continuous mixing at the site, and batch mixing at the site.

Ready-mixed concrete is typically used for NRCS work. Ready-mixed means that the concrete is batched, mixed, and delivered to the site rather than being batched and mixed onsite. There are three types of ready-mixed concrete: central-, truck-, and shrink-mixed. Central-mixed is mixed in a rotating-drum stationary mixer. Truck-mixed is mixed in a rotating-drum truck mixer. Shrink-mixed is a combination of central-mixed and truck-mixed. These three types of ready-mixed concrete are further described in Construction Specification 31.

The industry standard specification for ready-mixed concrete is ASTM C94, Standard Specification for Ready-Mixed Concrete. This specification covers the production and delivery of a concrete mix to the point of discharge from the mixer.

Volumetric batching and continuous mixing employs an auger-type mixer. The auger is attached to a truck which contains bins for the aggregate and cement and a tank for the water (fig. 12–7). The bins discharge onto a belt or into an auger conveyer that conveys the dry ingredients to the mixing auger where water is introduced into the mix. The bins have adjustable doors that control the volume of material being discharged. The ingredients are mixed by the auger as the resulting mix is conveyed to the point of discharge.

Even though batching by volume is not as accurate as weigh-batching, these types of mixers are generally accurate enough for most NRCS work. They have the advantage over ready-mixed concrete in that the exact quantity needed can be produced-on-demand without a time delay between batching and placing. These are ideal for small on-farm pours that are common

Table 12–4 Batch ticket requirements

	Method of producing concrete mix	
	Ready-mixed	**Volumetric batching and mixing**
Required by	**ASTM C94**	**ASTM C685**
Name of supplier and batch plant designation	X	X
Delivery ticket number	X	X
Date	X	X
Start and finish time		X
Batching and mixing equipment I.D.		X
Truck number	X	
Time of loading	X	X
Time of discharge	X	X
Name of purchaser	X	X
Job name and location	X	X
Class or designation of concrete	X	X
Cubic yards batched and mixed	X	X
Revolution counter at time of loading	X	
Revolution counter at time of discharge	X	
Drum revolution limit	X	
Type, brand (as applicable), and quantity of each ingredient	X	X
Amount of water added after batching	X	
Information needed to calculate the total mixing water	X	X
Maximum size of aggregate	X	X
Signature or initials of producer's representative	X	X

in some conservation engineering work and for concrete being placed in remote areas where the distance from a ready-mix plant makes it difficult to deliver the concrete before it begins to set up. These are at a disadvantage when it comes to mixing concrete with admixtures. The mixing action supplied by a volumetric batch and continuous mix truck is generally not adequate for providing the required mixing action needed by admixtures to perform as intended. ASTM C685, Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing, is referenced by Construction Specification 31. The inspector should verify that volumetric batching and continuous mixing conforms to ASTM C685.

Batch mixing at the site requires a portable batch plant with a source of clean water, silos for the cementitious materials, bins for the aggregate, and a mixing drum or mixing auger. It also requires a scale for weighing the truck as it is charged with ingredients or calibrated load cells that provide ingredient weights. The plant should produce a batch ticket showing the amount of each mix ingredient added to the batch.

ASTM C94 lists the items that are required to be on the batch ticket for ready-mixed concrete C94. For volumetric batching and continuous mixing the required batch ticket information is listed in ASTM C685. Table 12–4 lists the items required by C94 and C685 for batch tickets for the two methods of producing concrete.

Sometimes the w/c is shown on the batch ticket and the amount of water that can be added without exceeding the maximum w/c may also be shown on the ticket. Even if the w/c is shown on the ticket, it is good practice to compute the w/c from the batch ticket information and verify that the maximum allowable w/c is not exceeded. Most batch tickets show the aggregate weight in the saturated surface-dry moisture condition. In order to compute the w/c, the batch ticket must make clear the aggregate moisture condition (dry, saturated surface-dry, or field moisture) for which the aggregate weights are reported.

The inspector must verify that the batch ticket contains the required information and that the batch ticket shows that the mix conforms to the specification and approved job mix requirements. For ready-mixed concrete, the inspector should obtain the batch ticket when the truck arrives onsite, verify the mix described on the batch ticket conforms to the specification and approved job mix, and judge that there is adequate time remaining to place the mix within the specified time. Check the drum revolution counter and verify that the revolutions are within the specified limit (Construction Specification 31 specifies a revolution limit of 300 revolutions).

If an additive is added at the site, it must be added with some water. Otherwise, adding an additive by itself could result in a concentration of the additive in only a part of the batch. The amount of water needed to prevent concentrating the additive in only a part of the batch is dependent on the batch size, but generally a few gallons will suffice. Water may also be added for the purpose of increasing slump up to one inch, as long as the maximum amount of allowed water will not be exceeded. Experience has proven that holding back some of the water at the batch plant and adding the held-back water at the site will result in a higher slump than if all of the water is added at the ready-mix plant. Generally, concrete suppliers hold back some of the mix water so that some water can be added at the site.

Tests for air content, slump, and concrete temperature must be made on a regular basis to verify and document that the mix complies with specification requirements and the approved job mix. These tests must also be made anytime strength test specimens (cylinders) are made. Minimum quality control testing frequency should be specified and quality assurance inspectors should test on a frequency required by the quality assurance plan. Cylinders must also be made as specified in the quality control specification and as required by the quality assurance plan. The specified or required frequency of testing should be taken as a minimum with additional tests made as needed to verify specification compliance. NEH645.1202, Sampling and testing, describes proper sampling and testing for verifying specification compliance.

Thorough documentation is required if a mix is rejected. Every effort should be made to avoid rejecting a mix, but if it must be rejected the contractor should be the one making the decision. When the contractor refuses to reject the mix, there should be clear factual documentation of all relevant discussions between all parties involved and a set of cylinders should be made by the quality assurance inspector. Whether the mix is rejected or placed, tests should be recorded to document the condition of the mix.

The inspector's responsibilities related to mixers and mixing include verifying:

- The size of the batch does not exceed the rated maximum capacity of the mixer
- For site mixed concrete, ingredients are introduced into the mixer in the proper sequence
- Problems with mix uniformity are investigated, corrected, and documented
- No water is added in excess of that specified and called for in the approved job mix
- The responsible engineer is called on when it is necessary to inspect an off-site plant
- Volumetric batching and mixing conforms to ASTM C685
- The batch ticket contains the specified information
- The w/c shown on or computed from the batch ticket does not exceed that specified and called for in the approved job mix
- The mix conforms to specification requirements and the approved job mix
- Adequate time remains to discharge and place the concrete
- Drum revolutions do not exceed the specified maximum
- Tests are made as specified or as needed to confirm specification compliance
- When strength test specimens (cylinders) are made, the air content, slump, and concrete temperature along with the batch ticket number are recorded and referenced to the cylinder identification numbers.
- Test results are documented
- Any actions taken related to rejection of concrete are thoroughly documented

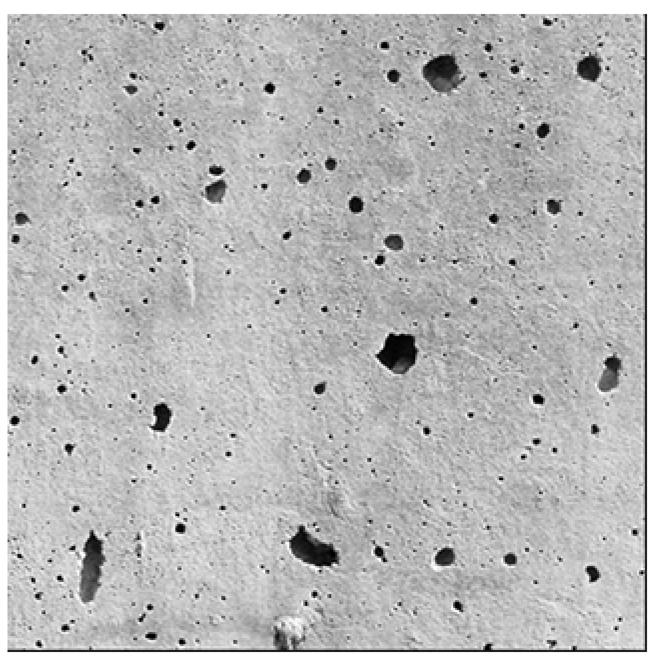
(f) Forms

Concrete forms must be tight, rigid, and strong enough to sustain the weight of the concrete, workers, and equipment. If not mortar tight, leaking (bleeding) of the mortar will cause *honeycombing* or *sand streaking*. Forms must be set to grade, aligned, and adequately braced. They must have adequate *falsework* where applicable. Internal spacers and form ties must maintain the position of forms during placement and consolidation. Tolerances for formed surfaces are given in sections 17 and 23 of Construction Specification 31.

Form release agents (commonly referred to as form oil) are used to prevent the concrete from sticking to the form, but must not be applied to construction joints or other bonding surfaces. Generally, a light coating of form oil is acceptable on the surface of deformed reinforcing bars, but not on smooth reinforcement. A heavy coating of form oil must be avoided on all bars. Apply form release agents to the forms before setting them in place to avoid getting any form oil on the reinforcement or bonding surfaces.

Form release agents used with superplasticized concrete must be specifically formulated to allow entrapped air bubbles to escape when the concrete is consolidated. Otherwise, air bubbles will remain in the concrete next to the forms resulting in what is called bug holes in the formed surface (fig. 12–9). A few bug holes are not detrimental to the concrete's function or durability; they are more of an aesthetic concern.

Figure 12–9 Bug holes in formed surface (blast journal.com)



Vertical forms are made of four components: sheathing, studs, wales (or walers), and tie rods (ties) or bolts (fig. 12–10 (a)). Horizontal forms are composed of sheathing, joists, stringers, and shores (posts) (fig. 12–10 (b)). Horizontal forms may also be secured with struts, guys, or cables.

Forming components are selected based on the maximum anticipated concrete pressure on the forms. Ambient air and concrete temperature, the inclusion of an accelerator or retarder in the mix, and the rate of pour affect form pressure. Figure 12–11 illustrates how form pressure is reduced as concrete hardens.

Figure 12–10 (a) Vertical form components, (b) Horizontal form components

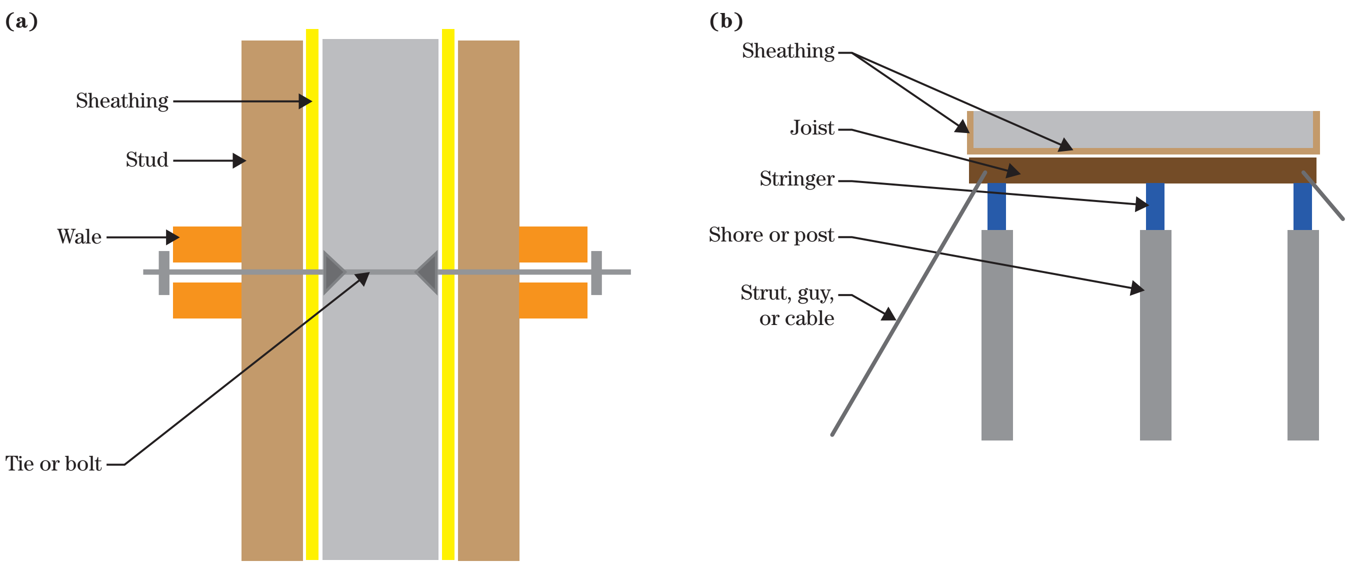
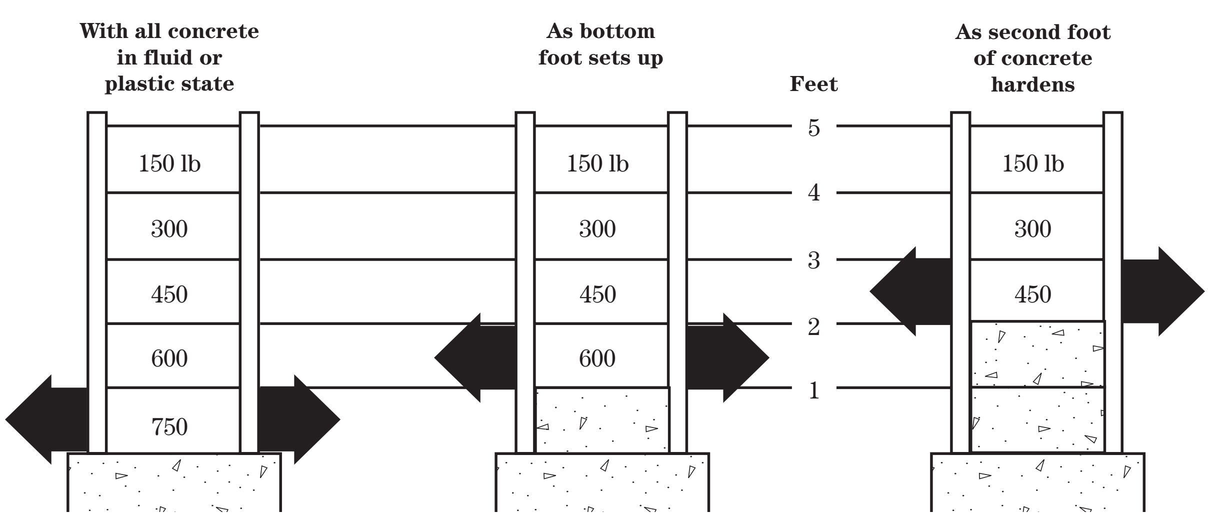


Figure 12–11 Concrete form pressure (lb/ft^3)

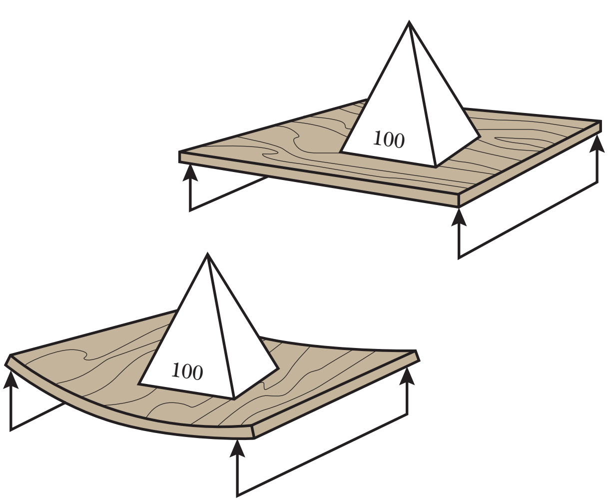


Form pressure will be relatively high with high placement rates and on cold days when temperatures slow the time of setting (retard set). Construction Specification 31 allows concrete made with a superplasticizer to be dropped up to 12 feet vertically. This causes the concrete to be placed rapidly and creates the potential for high pressures since there may be several vertical feet of *plastic concrete* in the forms.

The contractor is responsible for designing the forming system but the inspector should review it with the contractor to learn the assumptions made in the design. If the concrete is being placed in cold weather, contains a set-retarder, or will be placed at a relatively high rate, the form design may not be adequate. The contractor may be using a forming system design from a previous job that has not been modified for the job at hand. The inspector should ask the responsible engineer to assess the adequacy of the forming system if it is in question.

Sheathing is typically made from plywood that is stronger when supported in one direction than in the other direction. As illustrated in figure 12–12, supporting plywood across or perpendicular to the face grain is stronger than if the supports are aligned parallel with the face grain.

Figure 12–12 Plywood supported across the face grain (strong direction) and parallel to the face grain (weak direction)



Forming systems may be designed with the sheathing supported in the strong or weak direction. If the system is designed with the sheathing supported in the weak direction, the studs or joists will be spaced closer together than if it were oriented in the strong direction. The inspector should be aware of how the forms are designed with respect to the direction of the sheathing and verify that the sheathing is oriented as designed.

The strength of any wooden forming system is highly dependent on the condition of the wood. Form designs consider the condition of the wood with different requirements for wood that is reused and that of new one-time use wood. Most forms are designed for reuse, but the strength of wooden forms that have been used many times continues to diminish. Plywood becomes weaker with repeated cycles of wetting and drying. If plywood is not plyform designed for concrete sheathing or plywood designed to withstand water (e.g. marine plywood), it will have a short service life. When inspecting forms, the inspector must pay attention to the condition of the wood and voice concern if members are broken, cracked, bent, or otherwise appear to be damaged or in poor condition.

Studs support vertical wall sheathing and joists support horizontal sheathing. The studs are supported by the wales. If a wall is large enough, several studs and wales will be installed in a span end to end. The ends of these studs and wales must alternate from one span to the next to achieve what is termed a partially continuous span. This is illustrated in figure 12–13. Partially continuous spans are much stronger than those that are not partially continuous as shown in figure 12–14. This also applies to joists that support the sheathing for horizontal forms.

Wooden forming systems are always designed with partially continuous spans. The inspector should verify that they are installed as designed with the spans of studs and wales, or joists as applicable, being partially continuous.

Wall forms are held together with form ties made from metal, fiberglass, or plastic. Construction Specification 31 requires metal form ties to be designed so that the ties break off one inch below the formed concrete surface. A tie cone is installed around the form tie so that when the forms are removed the tie can be broken off one inch below the surface. Figure 12–15 shows (a) form tie cone installed, (b) forms removed, and (c) tie broken off one inch below the formed surface.

After the tie is broken off, the cone hole is cleaned and packed with a dry-pack mortar. Dry-pack mortar is made by combining one part cement and two parts fine sand with just enough water to form the mixture into a ball. It is then placed in the tie hole in two layers with each layer being compacted with a wooden stick and a hammer.

Figure 12–13 Partially continuous studs and wales, the desired system

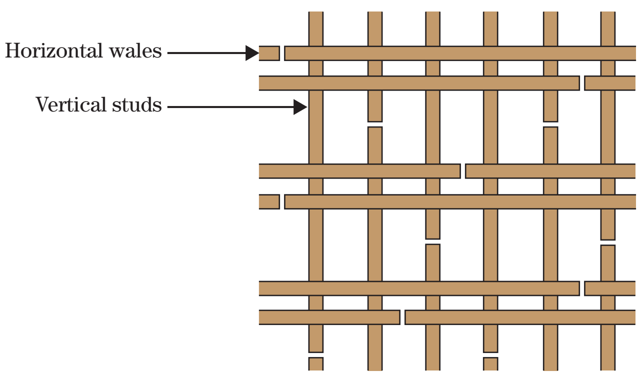
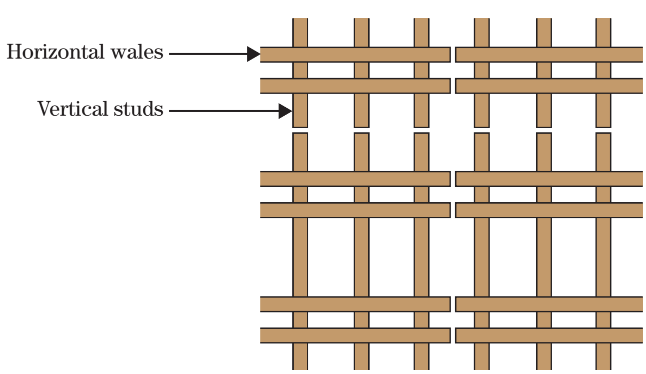


Figure 12–14 Studs and wales that are not partially continuous. This system is weak and should never be employed



Another method of tying forms is with the use of she-bolts. These are bolts that screw into a threaded form tie. The bolt may have a uniform cross section from head to end and require a cone as shown in figure 12–16 or may be tapered between the sheathing and threaded tie so that a cone need not be added to attain a tapered hole that can be cleaned and packed with dry-pack mortar.

Metal forming systems are available that are sold or rented as complete systems. These types of forms come in panels with connectors that allow the panels to be quickly assembled and taken apart. The panels have a smooth metal surface that can be used for sheathing, but plywood sheathing is sometimes affixed to the panels to protect and extend the life of the panels. For rented systems, plywood sheathing may be required by the rental company to protect the metal forming system. Although these types of systems are available as complete systems including struts and bracing, the forming contractor may use a combination of metal and wooden forming or otherwise retrofit the rented forms. The inspector should review the information provided by the forming system manufacturer to verify that the system is installed as designed.

Chamfered edges (fig. 12–17) are more durable than square edges that are susceptible to chipping when impacted. Construction Specification 31 requires chamfered edges be formed unless the edge is finished with a molding tool. Chamfered edges are formed by installing a triangle shaped piece of wood at all formed 90 degree corners.

A tooled edge (fig. 12–17) is molded where chamfered edges are difficult to form or where a molding tool is more efficient, such as at the exposed edge of slabs. The tool is a radius tool (a.k.a. an edger) that is hand pushed along the edge during the finishing process. The concrete must gain sufficient strength so as not to crumble under the pressure of the tool, but be weak enough so that it can be molded. Pressure is applied to further compact or consolidate the radiused edge of the concrete to make it stronger to resist chipping when impacted.

Figure 12–15 (a) Form tie cone installed; (b) Forms removed (c) Tie broken off one inch below formed surface

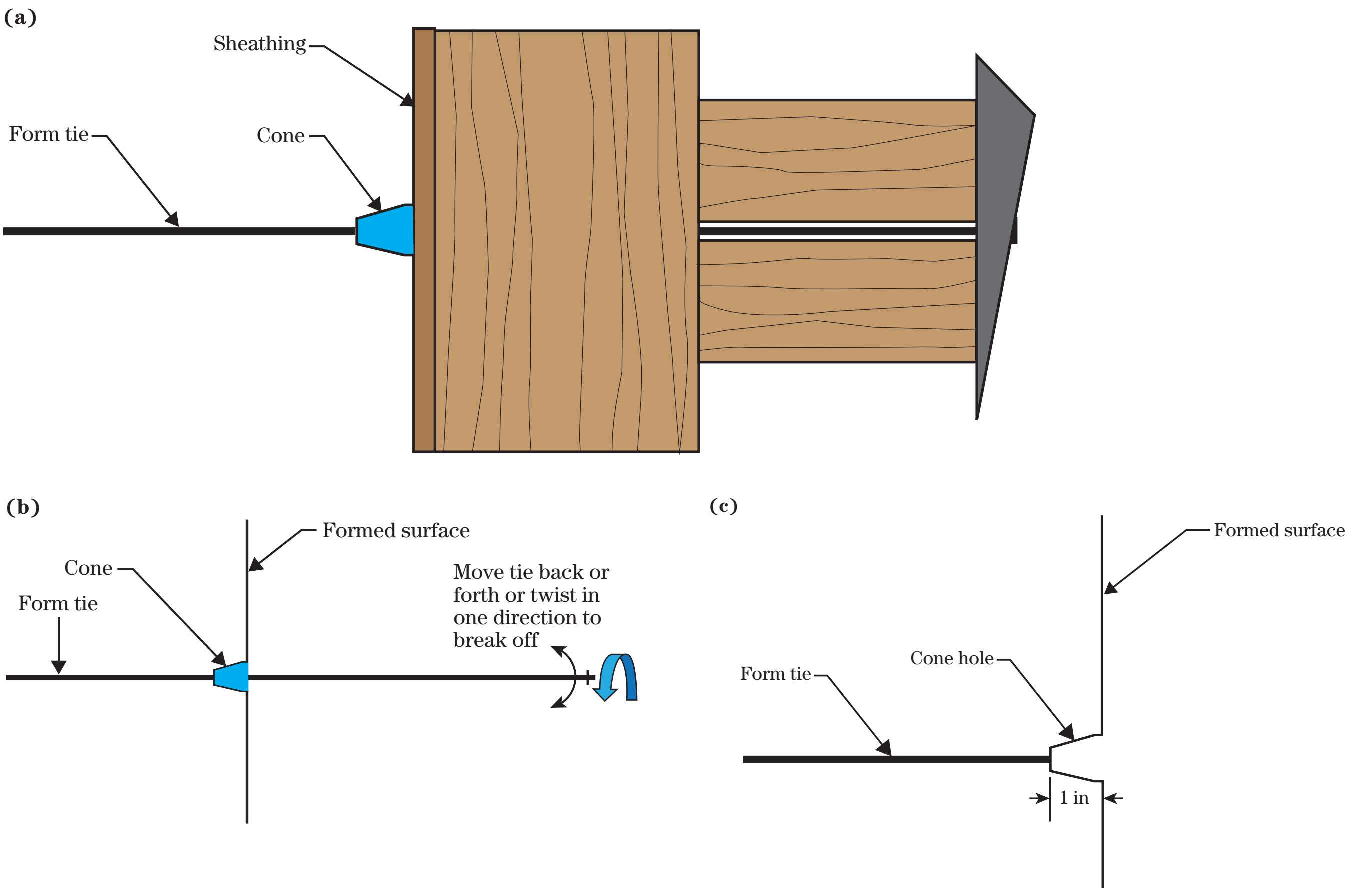


Figure 12–16 She-bolt form tie

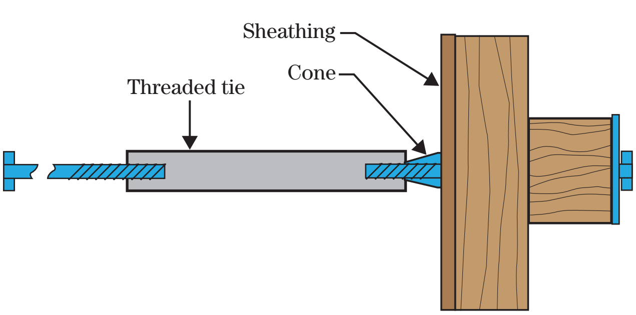


Figure 12–17 A tooled edge and a chamfered edge

The inspector's responsibilities related to forms include verifying:

- forms appear to be of good quality
- forms are mortar-tight.
- form surfaces (sheathing) are smooth and free of irregularities
- forms are properly installed and secured as designed
- forms are set to grade, positioned, and secured so that concrete is constructed within specified line and grade tolerances
- falsework is adequate to support the forms
- sheathing is oriented as designed
- wales and studs or joists are installed in partially continuous spans
- planned rate of placement will not exceed that used in the form design
- forms and rate of placement are adjusted to account for cold weather, retarders, and superplasticized concrete
- form release agents are used per manufacturer's instructions
- form release agents are formulated for superplasticized concrete if applicable
- bonding surfaces and smooth reinforcement are kept free from form release agents.
- any amount of form release agent more than a light film is removed from reinforcing bars
- If specified, metal form ties contain cones, she bolts or other devices that allow for removal of the tie to a depth of at least one inch below the formed surface
- If applicable, the specified size of chamfer strip is installed

(g) Preparation of forms and subgrade

Concrete will be placed on earth, rock, forms, or previously installed concrete. The subgrade and all embedments must be clean and free of form oil and standing water. For reinforced concrete, reinforcement must be installed and secured prior to ordering concrete.

All embedments such as conduits, wall thimbles, and waterstops must be secured in the designed location. Metal embedments must be nonferrous material. Forms may have to be vented to avoid trapping air under large embedments such as pipes.

Foundations that are frozen can severely retard the setting of the mix and, if coupled with cold ambient air, can halt cement hydration. Additionally, frozen foundations tend to be soft when thawed and provide poor support for concrete. Ice, snow, or frost which is trapped under concrete will result in a void that will weaken support for the concrete above.

Soil foundations must be compacted to a uniform density that will support construction loads and concrete in service. Having uniform support reduces the potential for differential settlement of the foundation and concrete.

Soil foundations must be moist to prevent water from being absorbed from the concrete. If water is absorbed into a dry foundation, there may be inadequate water remaining to fully hydrate the cement and inadequate bleed water that would otherwise help limit plastic-shrinkage-cracking. Standing water must be removed from any foundation to prevent high w/c causing weak concrete. Standing water may also become entrapped in the concrete.

Concrete slabs must not be placed on plastic or other impermeable barrier that will prevent the bottom of the slab from bleeding. If water cannot escape through the foundation there will be added bleed time causing delayed finishing or finishing before bleeding ceases. Also, the concrete surface may dry while bleed water is trapped in the bottom. The bottom is prevented from shrinking as much as the surface which can cause the slab to curl. If an impermeable barrier must be installed under a slab, a few inches of moist sand must be placed between the barrier and concrete to allow a normal bleed. Geotextile material can be used as an alternative to impermeable materials if needed to help support reinforcement and provide a clean subgrade on which to work and place concrete.

Rock foundations must be clean and free of loose rock and debris. Negative slopes or overhangs must be removed to allow intimate contact between the concrete and rock.

Where concrete is to be bonded to existing concrete, the existing concrete must be clean and treated as specified. Treatment may include flushing with water, scrubbing with a wire brush, sand blasting, or a combination of these to ensure concrete is clean and free of form oil and curing compound. When the concrete being placed is to be bonded to old existing concrete, a bond enhancement may be needed. Bond enhancements such as neat cement grout, latex, or epoxy may be applied to the bonding surface immediately prior to installing the new concrete. Be aware that latex bonding agents must be covered with concrete in a timely manner because, if they set up before placing concrete over or against them, they will act as a bond breaker. See NEH645.1201(l), Joints, for more on bonding to old concrete.

The inspector's responsibilities related to preparation of forms and subgrade include verifying:

- The subgrade and all embedments and reinforcing steel are clean and free of form oil and standing water
- All embedments are secured in the designed location
- Metal embedments are nonferrous material
- Vents are installed to avoid trapping air under large embedments
- Foundation is not frozen
- Foundation is moist and compacted as specified
- Impermeable barriers are overlain with sand or geosynthetics that will allow the concrete to bleed downward
- Rock foundations are clean and freed of loose material
- Rock foundations are free of negative slopes or overhangs
- Bonding surfaces are clean, free of form oil and curing compound
- Bonding surfaces are treated as specified

(h) Steel reinforcement

Delivery of reinforcing steel must be observed and documented by the inspector. The steel may simply be straight bars or be fabricated by cutting and bending. It should be bundled and tagged for identification; this is especially important for fabricated steel since it must be placed in a specified location within the structure.

Generally, each bundle contains bars of one size, length, mark, and the same bend or bends. Various methods of tagging are used, but each bundle's tag must show the purchaser's name or order number, number of pieces, bar length, and where each piece will be located in the structure. The exception would be for a job where only straight bars of the same size are used such as for a flat slab on grade.

Upon arrival, the contractor is to obtain a delivery ticket listing all of the delivered materials. The ticket must identify the job by name to avoid taking delivery of steel that is designated for a different jobsite. If not provided before delivery, any bar-bending and placing diagrams prepared by the fabricator must be provided by the delivery truck driver. The inspector must obtain a copy of all paperwork given to the contractor at the time of delivery and verify the materials delivered are the correct materials for the job.

Steel rebar must be stored on supports in an onsite location that is convenient to the location of placement. It must be kept above ground to remain free of mud. Bundles to be placed last must be offloaded first with the bundles organized so that rebar can be extracted from the top of the pile as needed.

Placing steel exactly as shown on the drawings and ensuring it stays there is critical in the successful performance of any reinforced concrete structure. Each bar must be oriented as specified on the drawings and must be secured with tie wire. The following placement tolerances are recommended by the Concrete Reinforcing Steel Institute (CRSI).

- Where 1 1/2 inch distance is required between reinforcing bars and forms, allowable clear distance is 1 1/8 to 1 1/2 inches.
- Where 2 inches distance is required between reinforcing bars and forms, allowable clear distance is 1 5/8 to 2 inches.
- Where 3 inches distance is required between reinforcing bars and earth or forms, allowable clear distance is 2 1/2 to 3 inches. Overexcavation

backfilled with concrete does not count toward clear distance.

- Maximum variation from indicated reinforcing bar spacing: one-twelfth of indicated spacing, but there must be no reduction in the number of bars placed from that specified.
- The ends of all reinforcing bars must be covered with at least 1 1/2 inches of concrete.

Tack welding of bars is not permitted as it can weaken the steel. For the same reason, bars must not be heated when bending or spliced by welding.

The minimum lap splice length should be specified or indicated on the drawings (fig. 12–18). If not specified or indicated on the drawings, ask the designer for the minimum lap splice length. The inspector must verify the minimum lap splice length is attained for all lapped bars.

Welded wire fabric (WWF) is manufactured in long runs that are cut to length. The ends are cut between transverse wires resulting in an overhang of the longitudinal wires. When splicing one end of a panel to the end of another panel, the panels should overlap a length of one full mesh opening plus 2 inches plus the overhang length. The sides of WWF panels do not have the overhanging wires. When splicing two panels side to side they should be lapped a distance of one mesh opening plus 2 inches (fig. 12–19).

Reinforcing steel must be supported with materials that are not prone to rusting. Holding steel reinforcement in position with temporary supports is not permitted. It is common for concrete contractors to want to lay the steel on the ground and pull it up into position as slab concrete is being placed. This is not allowed as it makes it impossible to verify the exact location of the steel in the concrete and there is no

Figure 12–18 Lap splice length

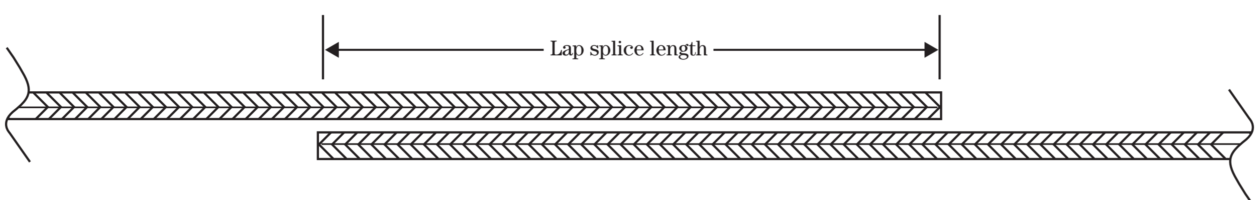
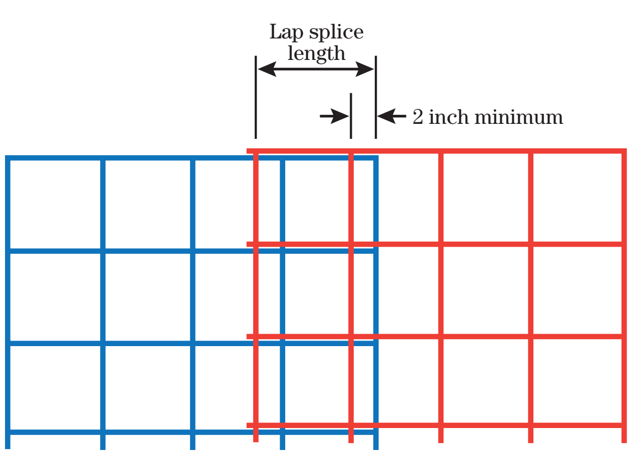


Figure 12–19 WWF lap splice length



guarantee that the steel will stay in position without adequate support. Metal chairs, metal hangers, metal spacers, high density or structural plastic rebar accessories or concrete bricks (not clay bricks) may be used to support reinforcing steel.

In vertical forms, the steel must be secured in place. Metal hangers, spacers, and ties must be placed so that bare ferrous metal is not exposed in the finished concrete surface. The legs of metal chairs or side form spacers that will be exposed on any face of slabs, walls, beams, or other concrete surfaces must be stainless steel or have a protective coating or finish. The coating or finish can be hot dipped galvanizing, epoxy coating, or plastic coating.

Precast concrete chairs (blocks) used to support steel bars in slabs must be clean and moist at the time concrete is placed. These are often made from the same concrete as is being placed or may be purchased from a supplier of concrete construction products. Clay bricks must never be used as they are not as strong as the concrete and can weaken the slab. Concrete chairs must have sufficient strength to support the load. They are often made with tie wire partially embedded in the concrete chair. The tie wire helps hold the chair in place and keep it from tipping over as it is tied around the bar being supported by the chair (fig. 12–20).

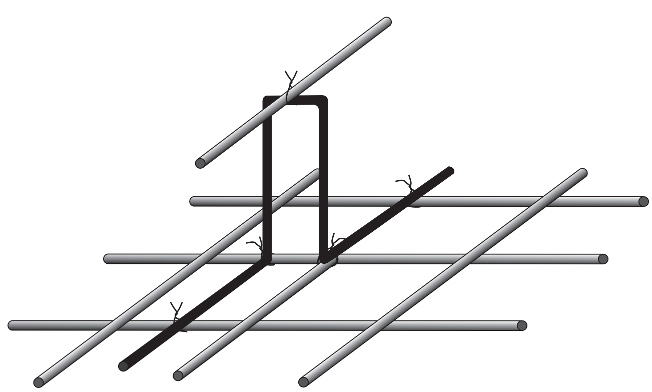
Double layers of reinforcing steel are generally held apart by standees. These are made from rebar that is bent as shown in figure 12–21. Like concrete chairs, standees should have sufficient strength and be spaced close enough to support the load and prevent deflection of rebar.

Reinforcing steel must never be placed until the prepared site has been inspected by the NRCS inspector. The inspector must inspect the in-place reinforcement before concrete is ordered and again prior to and during concrete placement. Inspect the steel for proper location, orientation of bent bars, spacing and clearance between steel and forms, lap splice length, adequate tieing and support, and cleanliness.

Concrete placement must cease if steel movement is observed and not resume until the steel can be secured so that it stays in place during the concrete placement. Workers may stand on reinforcement causing it to flex as they work to place the concrete; this is not a concern as long as the reinforcement returns to its specified location as the work progresses.

Figure 12–20 Concrete chairs with tie wire

Figure 12–21 Standee



The inspector's responsibilities related to the placement of steel reinforcement include verifying that:

- When delivered, steel is adequately bundled and tagged.
- Copies of all paperwork provided by the delivery driver are checked to verify it is the correct steel for the job.
- Steel is offloaded and stored in a manner that will allow it to remain free of mud or contaminants and will promote efficient extraction from the pile.
- The foundation is to grade and compacted to the specified density prior to steel placement.
- Materials required between the slab and the earth are in place prior to steel placement.
- The correct size, shape, grade, and length of steel is placed and secured in the correct location.
- Splice lengths are adequate and appropriately located as specified or as shown on the drawings.
- Bars are supported and secured so they do not move during concrete placement.

(i) Conveying

After batching and mixing, concrete must be delivered and placed before it begins to set up. It must also be conveyed in a manner that will not cause the individual ingredients in the mix to separate (segregate). In hot weather, concrete tends to set up faster than when it is cool. In hot weather or when the concrete temperature is at or above 85 degrees Fahrenheit, concrete may begin to set up in as little as 45 minutes from the time the water is introduced to the cement. When it is cooler, the time to the initial set is generally longer than 1 1/2 hours. A set retarder can be added to the concrete mix to allow more time before the concrete begins to set up.

For ready-mix concrete delivered in a rotating drum mixer, the number of drum revolutions must be observed. Keeping concrete in a revolving drum for an extended number of drum revolutions can damage the mix, especially in hot weather. Concrete that has revolved in a drum for extended periods may look whiter than concrete that has revolved a limited number of revolutions. The over-mixed concrete will be weaker and less durable than concrete that is only mixed an appropriate number of revolutions.

At one time ASTM C94, Specification for Ready-Mixed Concrete, limited the number of drum revolutions to 300 revolutions. In 2014 the ASTM removed the revolution limit because, in many instances, concrete can be mixed more than 300 revolutions and still be of acceptable quality. ASTM recognized the problems caused by a hard and fast upper limit on revolutions because many owners and agencies were rejecting good concrete just because it had revolved over 300 revolutions. NRCS has not removed the limit on the maximum number of revolutions from Construction Specification 31.

Regardless of the number of revolutions or the time elapsed between beginning mixing and placing, it is important to know how to judge the concrete mix to determine if it is beginning to set up. This can be done by immersing a properly working immersion vibrator into the mix and observing the concrete as the vibrator is extracted from the concrete. If the hole made by the vibrator immediately closes when the vibrator is removed, the concrete is still fresh enough to continue placing, consolidating, and finishing. If the hole made by the vibrator does not close or is slow in closing after the vibrator is removed from the concrete, stop conveying concrete from the truck.

Segregation of a concrete mix can happen when conveying concrete from the mixer to the point of placement. The more the concrete is handled, the more potential there will be for segregation. There is potential for segregation when concrete is discharged into a concrete bucket or loader bucket and conveyed to the point of placement. Limiting the drop height when concrete is transferred from one container to another and limiting the number of transfers will help limit segregation.

Concrete is sometimes conveyed to the point of placement by a concrete pump. This method of conveying concrete has the advantage of delivering concrete in a continuous stream that can easily be moved horizontally and vertically. One caution is that the slump and air content will be reduced by pumping. Air entrained concrete that has a high water to cement ratio can suffer up to three percent air loss. Concrete slump and air can be increased before pumping to mitigate the potential loss in slump and air caused by the pumping process. Water may be added to increase slump if some of the water has been held out of the mix so that the addition of water does not cause the w/c to be over the maximum allowed in the job mix. Additives such as superplasticizer may be added as long as some water may be added to help evenly distribute the additive within the batch.

There are several mechanisms that cause the loss of air in pumped concrete. High or surging pump pressures can collapse air bubbles. Another mechanism for air loss is the vacuum that occurs in the pump line if a slug of concrete slides down the pipe. This is generally caused by friction between the inside of the pump line and the concrete that prevents smooth concrete flow. The vacuum in the upper end of the pipe greatly expands the size of the air bubbles. These expanded air bubbles collapse when the concrete hits an elbow in the boom or hits the surface upon which it is discharged.

Conveyor belts can be used to transport low slump concrete, but are generally not used for higher slump mixtures due to segregation potential. Low slump mixes will also segregate on belts that are significantly inclined. Conveyor belts must be equipped with a scraper that prevents mortar from remaining on the belt when the concrete is discharged from the belt. A baffle (wood, steel, or heavy flexible material like a mud flap) should be positioned just beyond the end of the belt to prevent propelling the mix off the belt causing it to segregate. Segregation can also occur if the mix drops or falls more than five feet as it is discharged from the end of a belt. Tremies or elephant trunks should be used to prevent the mix freefalling more than five feet.

On jobs where concrete is conveyed long distances by belt, the belt must be covered to protect the concrete from sun or rain.

The inspector's responsibilities related to conveying concrete include verifying that concrete:

- is conveyed to point of placement within the allotted time and before it begins setting
- quality has not suffered from too many drum revolutions
- that cannot be placed and consolidated with an immersion vibrator is rejected
- does not segregate when it is being conveyed
- that is pumped has the specified air content and slump at the point of placement
- conveyed by conveyor belt is protected from sun and rain

(j) Placing

Sometimes the specifications require a placement plan. Placement plans may be needed when planning for cold weather concreting or hot weather concreting, when the volume to be placed is large and a plan is needed to ensure adequate resources are available and to avoid unnecessary cold joints, or for other reasons that cause the specification writer to require a placement plan. The placement plan must be submitted and concurred in by the responsible engineer prior to ordering concrete.

Before placing concrete the inspector must verify that the *substrate*, forms, reinforcement, and embedments are ready for placement. Bonding surfaces must be prepared and treated as specified. For formed concrete, the inspector must look in the forms to verify that bonding surfaces are clean and free of debris. Bonding mortar or bond enhancements must be applied just prior to covering the bonding surface with fresh concrete. Some bond enhancements, latex for example, can become a bond breaker if applied too early and allowed to set up before being covered with fresh concrete.

Verify that forms around large embedments are vented below the embedment to allow entrapped air to escape. Otherwise, a void may occur below the embedment as was shown in figure 12–22.

Before ordering concrete, labor and equipment needed to convey, consolidate, finish, cure, and protect the concrete must be standing by in good working order. At least one working backup vibrator must be on site. If electricity is required to run the vibrator, a backup electrical source may also be needed. For cold weather concreting, all equipment needed to protect and insulate the concrete must be on site prior to ordering concrete. Supplemental heat should also be available, if needed, to keep the air near the concrete within the specified range.

When the concrete truck arrives, the contractor's quality control inspector must obtain a copy of the batch/delivery ticket. The ticket must be reviewed to verify that the approved job mix has been delivered and to determine if additional water can be added to the mix. The NRCS inspector must obtain and retain a copy of the batch/delivery ticket.

Water may be added to the truck as long as the water/cement ratio specified in the specification and approved job mix is not exceeded. All of the water must be added before concrete, other than a small amount sampled for testing, is discharged from the truck; otherwise, the amount of concrete in the truck will be unknown and the w/c cannot be determined.

Water must be thoroughly mixed into the concrete mix to avoid having a high w/c at the beginning of the load. If water is not thoroughly mixed into the concrete mixture, the first concrete discharged from the load will have a noticeably high slump and high w/c. Make sure the contractor and truck driver know water can only be added before concrete is discharged, and they need to mix the load 30 revolutions at mixing speed after adding the water.

Figure 12–22 Void in concrete below pipe

Additives that are added at the jobsite must be added with some water and the mixture thoroughly mixed to incorporate the additive and water and distribute both throughout the entire batch. Sometimes the truck driver will combine the additive and some water in a 5-gallon bucket before dumping it into the mixing drum. Others will pour the additive into the stream of water that is discharged directly into the drum before mixing it into the mixture. Either method is acceptable. After the addition of any additives or water, the drum should be rotated a minimum of 30 revolutions at mixing speed to fully incorporate the additives and water into the mixture.

Tests for slump, concrete temperature, and air are made to determine if the mix complies with the specified ranges and limits of each. Concrete can only be rejected for a failed test if the test is made on concrete sampled in accordance with ASTM C172/C172M, Standard Practice for Sampling Freshly Mixed Concrete. ASTM C172/C172M requires that ready-mixed concrete be sampled by taking two or more portions at regularly spaced intervals during discharge of the middle portion of the batch. But, it may be desirable to test the concrete near the beginning of the discharge to avoid placing concrete that is potentially noncompliant with the specification.

There is nothing wrong with testing at the beginning of the load discharge, but the test results cannot be used to reject the load. If concrete is tested at the beginning of the load and it is hotter than the maximum concrete temperature allowed specification requirements will not be met at the middle of the load. If the slump is significantly above the specified maximum at the beginning of the load, it is likely going to be above the specified maximum at the middle of the load. Also, if the air content is too low at the beginning of the load, it is unlikely that it will increase without adding more air entraining additive. Therefore, when problems are suspected it is good practice to test the concrete before putting it in the forms. The concrete cannot be rejected by the owner or owner representative based on tests that are not made from samples obtained in accordance with ASTM C172/C172M.

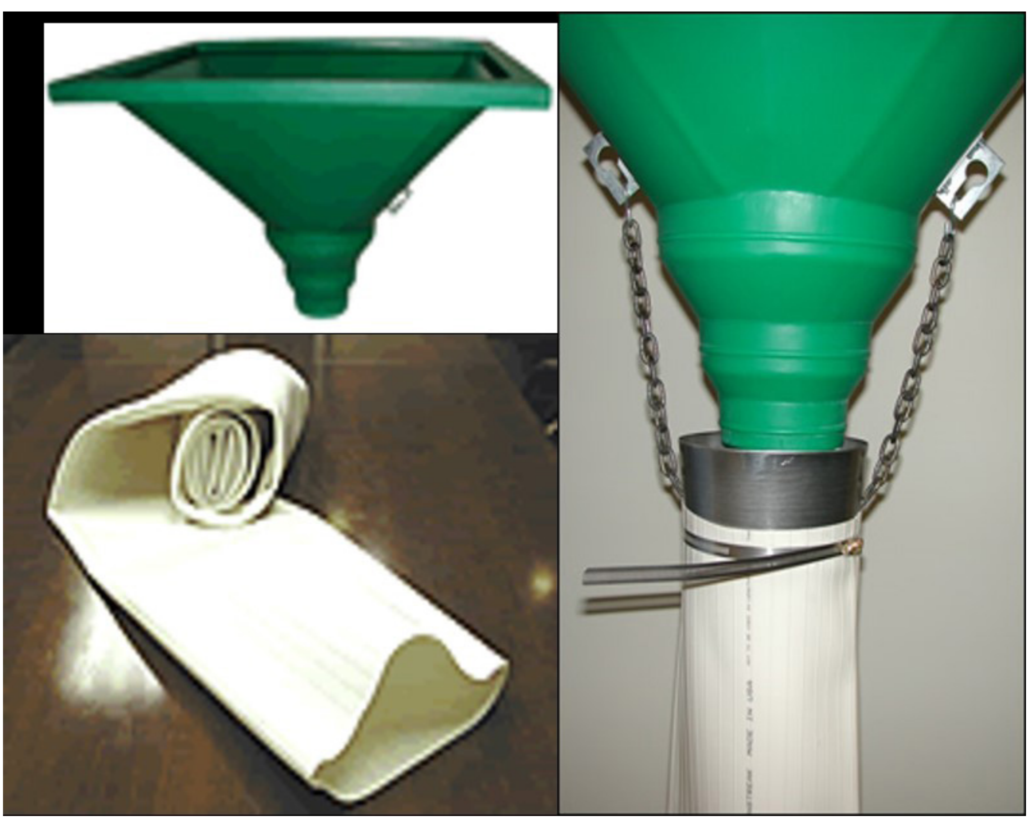
Placement can begin after all of the preplacement tasks are completed and concrete that appears to be specification compliant is available to be discharged and conveyed to the point of placement. The focus should be on getting the concrete into the forms, getting it consolidated, and finishing the concrete with minimal segregation. It is important to understand the various mechanisms that cause concrete to segregate in order to recognize the potential for segregation.

One cause of segregation in concrete is dropping it from a height greater than five feet. The heavier coarse aggregates fall faster than the smaller particles which leads to segregation. If coarse aggregates drop onto a hard surface they tend to bounce which also results in segregation. If the concrete is being dropped into forms that contain reinforcing steel, the coarse aggregate will bounce and ricochet off the rebar causing it to segregate even more. One way to prevent this is to use a tremie as seen in figure 12–23. The tremie is placed inside the forms allowing the concrete to flow through without impacting the steel. A tremie that is restricted at the bottom will fill with concrete so that once in the tremie the concrete will move through without segregating. But a tremie that is full of concrete will be heavy and may tear under the load. A full tremie can get lodged or jammed in between the rebars preventing the concrete from freely flowing and not allowing it to be moved or extracted. The tremie does not have to be full to help limit segregation.

As the concrete is being deposited a pile with sloping sides will be created. Coarse aggregate will roll down the sides of the pile causing segregation. This generally occurs in vertical forms if the concrete is allowed to pile up 20 inches high or more. Also, as the concrete piles up higher than 20 inches, it may begin to flow laterally; which can result in segregation, especially if it flows through and around reinforcing steel.

As the concrete is being deposited, it should be deposited into previously placed concrete in a manner that will allow all particles to stop and not continue to

Figure 12–23 Tremie



move. Placing concrete on a slope and allowing it to roll down the slope will cause it to segregate. Deposit the concrete in a manner that will allow it to come to rest and not continue to flow or move after deposited. Figure 12–24 illustrates the wrong and correct ways to deposit concrete to limit segregation.

After the concrete is deposited segregation will cease unless the concrete is moved laterally. The mechanism of segregation when moving the concrete laterally depends on how the concrete is moved. Workers like to use the vibrator to help mobilize the concrete. This can cause coarse aggregate to settle downward as the remainder of the mix moves sideways. If a rake is used to move concrete, the coarse aggregate can be pulled out of the mix so that the coarse aggregates are raked away from the mortar.

Low slump concrete tends to segregate less than that with a high slump. The coarse particles in low slump concrete are kept from segregating because the thicker mortar resists particle movement.

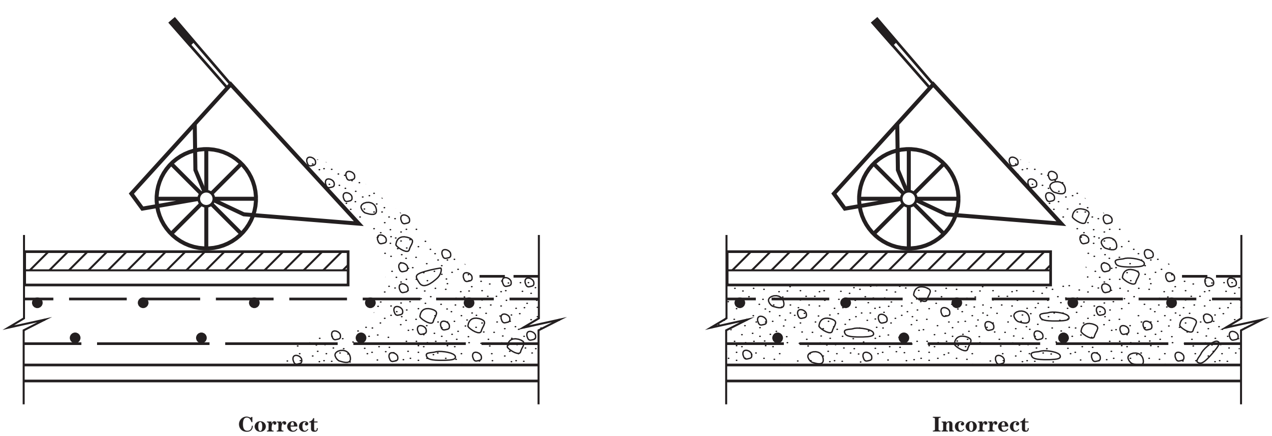
A high slump may exist, Superplasticized concrete that is made by adding a superplasticizer to low slump concrete tends to react like a low slump concrete when it comes to segregation. Specifications that restrict drop height to 5 feet will allow superplasticized concrete to be dropped up to 12 feet. Specifications that limit concrete layers to 20 inches will allow layers up to 5-feet deep if the concrete is superplasticized.

The inspector must observe placement and verify that concrete is not being dropped over 5 feet or over 12 feet if the concrete is superplasticized. Also, check the layer height to ensure layers are not over 20 inches in height or 5 feet, if the concrete is superplasticized. Verify that concrete is not being moved laterally for any significant distance after it is deposited.

A cold joint can occur when placing fresh concrete against any concrete bonding surface that has already been set. The rate of placement is important to limit cold joints.The objective when placing concrete in a vertical form is to place at a high enough rate so that as concrete is placed on the preceding layer it can be tied to the preceding layer without out the formation of a cold joint. For slab concrete, the placement plan should take into account the potential for cold edge joints and placement should be laid out to limit cold edge joints.

The inspector must verify that every effort is made to limit cold joints during placement. If concrete placement stops unexpectedly for any reason, there may be a need to bulkhead or shape the concrete to provide an acceptable surface on which to place concrete when placement resumes. In walls that do not contain horizontal reinforcing steel, a bulkhead can be inserted into the forms to allow the end of a layer to be formed vertically to avoid a sloping surface with potential featheredges at top and bottom. The vertical bulkhead must not be located against vertical rebar;

Figure 12–24 Wrong and correct ways to deposit concrete from a concrete buggy



it must be centered between vertical rebar so that the vertical rebar is as far from the cold joint as possible. For slab concrete, forms can be inserted or the edge of stiff concrete can be formed with hand tools to provide a near vertical surface. For both vertical formed concrete and slab concrete, bulkheads and forms will allow the concrete to be fully consolidated at the stopping point. Otherwise, if the concrete cannot be retained by a bulkhead or form, consolidation by vibration will cause the concrete to flow. In this case the flowing concrete will segregate and likely be under-consolidated.

The inspector's responsibilities related to placing concrete include verifying that:

- When applicable, the placement plan is concurred in by the responsible engineer.
- The substrate, forms, reinforcement, and embedments are ready for placement.
- Bonding surfaces are prepared and treated as specified.
- Bonding surfaces are clean and free of debris.
- Forms around large embedments are vented below the embedment.
- All necessary equipment and labor needed to convey, consolidate, finish, cure, and protect the concrete is available before ordering concrete.
- The approved job mix is delivered and specification compliant.
- A copy of the delivery/batch ticket is retained for NRCS records.
- No water is added in excess of that allowed by the approved job mix.
- Additives added on site are added with some water.
- The mix is mixed a minimum of 30 revolutions at mixing speed after the addition of water or additives.
- Efforts are made to determine that the concrete mix is specification compliant before it is placed.
- Record test results and test results used as a basis for concrete rejection are taken from tests made on concrete sampled according to ASTM C172/C172M.
- Drop heights and layer heights are limited to that specified.
- Lateral movement is limited after concrete is deposited.
- Every effort is made to limit cold joints.
- Bulkheads are installed and edge joints are formed and shaped when concreting is stopped for a significant length of time.

(k) Consolidating

Entrapped air causes concrete to be weak and permeable. Entrapped air bubbles are generally large enough to be seen by the naked eye (macroscopic). Before consolidation, concrete can have 5 to 20 percent of its volume occupied by entrapped air. Concrete is consolidated to remove entrapped air. This may be done by hand tools such as shovels and rods or by internal or external mechanical vibration. On thin slabs less than 8 inches thick external surface vibration can be effective.

Spading with a flat bladed shovel is commonly employed to consolidate thin slabs. Hand spading is appropriate only on small areas of relatively thin slab work. Internal and external vibration should be supplemented by hand spading on the exposed faces along the forms. Hammering the forms to consolidate the concrete is ineffective and not recommended. The contractor may suggest hammering because it is thought to be effective since it generally improves the surface appearance by helping to dispel air trapped against the forms.

External vibration is used in many precasting operations and for some slab work. A vibratory screed may be used in slab work, especially for highway slabs. For complete consolidation throughout the full slab depth, slabs over 8 inches thick will require internal vibration even if a vibratory screed is used. Thinner slabs may also require internal vibration, especially if the concrete slump is low. Reinforced slabs made of poorly consolidated concrete may settle over the reinforcing steel causing a checkerboard effect and cracking that would otherwise not occur if the concrete had been adequately consolidated.

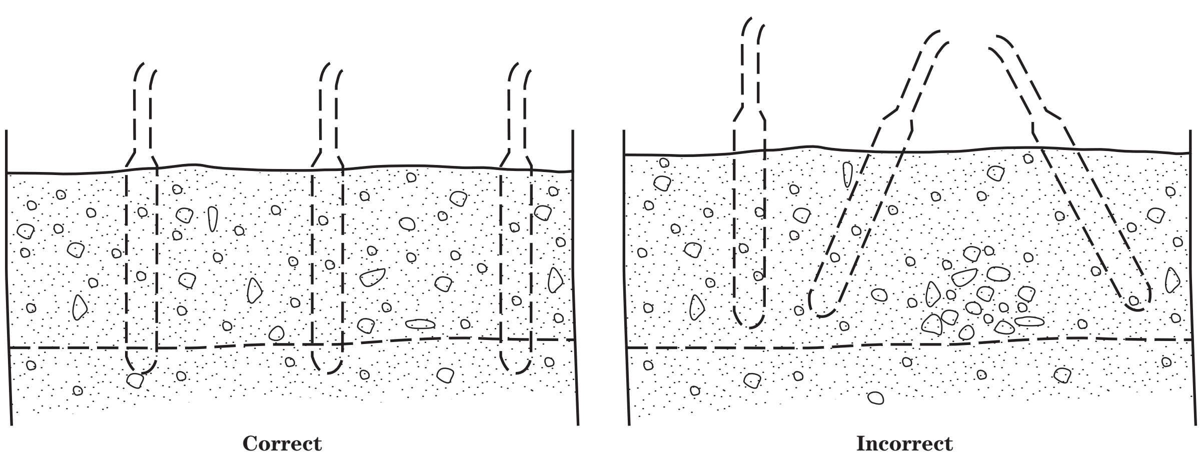
Form vibrators and vibrators that attach to rebar are used in some applications, but are disallowed by some specifications because they can subject the forms and steel to loading beyond that considered by the designer. Internal (emersion) vibrators must never be affixed to forms or reinforcing steel as this can damage the vibrator and is ineffective at consolidating the concrete.

Internal vibrators are commonly used to consolidate concrete in walls, columns, beams, and thicker slabs. The formation of an excessive amount of paste at the vibrator insertion point can indicate too much vibration. Too much vibration can result in segregation and loss of entrained air, however, too little vibration is far more common. When concrete is properly consolidated all of the coarse aggregate will become embedded, the surface will be relatively level, a thin film of glistening paste will appear on the surface, and large air bubbles will cease appearing at the surface. Figure 12–25 illustrates proper and improper methods for internally vibrating concrete.

It is common for inexperienced laborers to be tasked with operating the vibrator. This often leads to disastrous results. The vibrator operator must understand and implement specific guidelines for proper operation of the internal vibrator. These are:

- ensure that the vibrator is the proper size for the maximum size of coarse aggregate
- ensure that the vibrator is operating properly
- ensure that a backup vibrator and backup power source is readily available
- rapidly insert the vibrator vertically through the concrete into the preceding lift a depth of six inches
- slowly withdraw the vibrator vertically at a rate of five to ten seconds per foot
- withdraw the vibrator at a slower rate if air bubbles continue to rise to the surface
- withdraw the vibrator at a higher rate if air bubbles cease appearing at the surface and there is a large amount of accumulated paste at the insertion point after vibration
- observe the radius of vibrator influence and reinsert the vibrator into the concrete at a point 1.5 times the radius of influence but no more than 14 inches from the last insertion point
- if a hole remains at the insertion point after the vibrator is removed, the concrete is becoming too stiff to consolidate by vibration
- never use the vibrator to move concrete laterally
- for thin slabs, completely immerse the vibrator horizontally

Figure 12–25 Proper and improper methods for internally vibrating concrete



The inspector's responsibilities related to consolidating concrete include verifying that:

- the method of consolidation is acceptable for the structure geometry
- internal vibrators are the proper size
- internal vibrators appear to be working properly
- at least one backup vibrator and power source is readily available
- the vibrator operator appears to be operating the vibrator properly
- the vibrator is withdrawn slowly and reinserted the proper distance from the last insertion
- all of the concrete is vibrated
- the vibrator is inserted and extracted vertically
- for thin slabs the vibrator is fully immersed horizontally in the slab
- the vibrator is not used to move concrete laterally
- large air bubbles cease appearing at the surface just before the vibrator is fully extracted
- all coarse aggregate is embedded below the surface after consolidation
- the consolidated concrete surface is near level with a thin film of glistening paste on the surface
- internal vibration is no longer permitted when a hole remains after the vibrator is extracted

(l) Joints

There are three types of concrete joints: contraction, expansion, and construction joints.

Contraction joints (a.k.a. control joints) are installed to control the location of cracking. The acceptable width of concrete cracks depends on the application and is determined by the designer. Some cracks occur only on the concrete surface, while others pass through the full depth of the concrete, but may be microscopic. Small cracks, such as these, are expected and generally are so small that water will not pass through them. Other cracks may be large enough that the designer chooses to control them so that they crack in a specific pattern and can be sealed if desired.

Concrete begins to shrink as soon as it is placed. Shrinkage occurs because of a change in paste volume caused by drying and the water consumed in the cement hydration process. Shrinkage also occurs as the concrete cools. The concrete is typically restrained in some manner so that when it shrinks the restraint prevents free movement, which causes tensile stresses inside the concrete. When these stresses exceed the tensile strength of the concrete, the concrete cracks randomly at weak points along a wall, in a slab, or at controlled locations that are intentionally weakened.

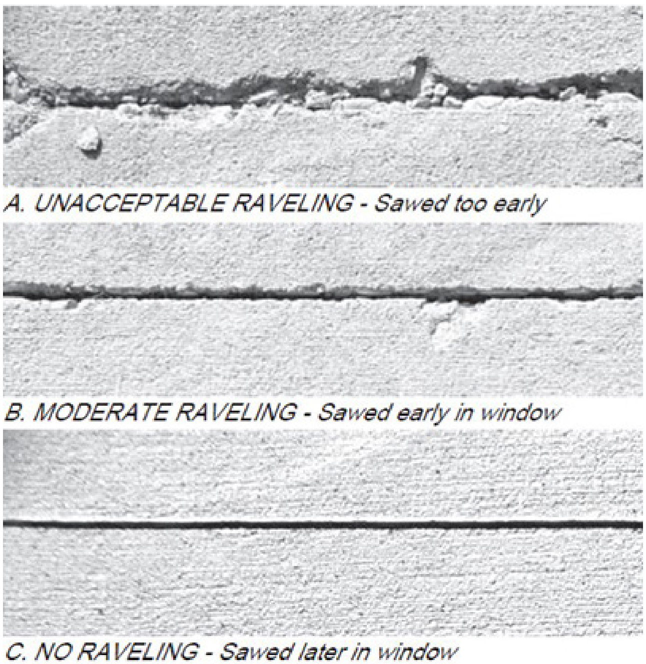
A common way to weaken a concrete slab to control the location of cracks is to cut a slot in the slab at uniformly spaced intervals. Timing of saw cutting is critical; if the concrete is sawed too early, it will ravel at the surface causing a rough unsightly cut. Sawing too late can cause the concrete to crack randomly ahead of the saw. Figure 12–26(a) illustrates the result of sawing too early and (b) too late.

Contraction joint spacing depends on the depth of the slab and the amount of paste in the mix. Since there is more paste in a mix with small graded coarse aggregate, concrete made with smaller maximum size aggregate (MSA) will shrink more than that made with larger MSA. For this reason contraction joints must be spaced closer together for small MSA concrete than for concrete made with larger MSA. Table 12–5 gives industry recommendations on the spacing of contraction joints for various slab thicknesses and aggregate sizes. These recommendations are for concrete with a slump between 4 and 6 inches. If the slump is less than 4 inches spacing may be increased 20 percent. In cold weather if the concrete cools significantly at an early age the contraction joints may need to be closer together than shown in the table.

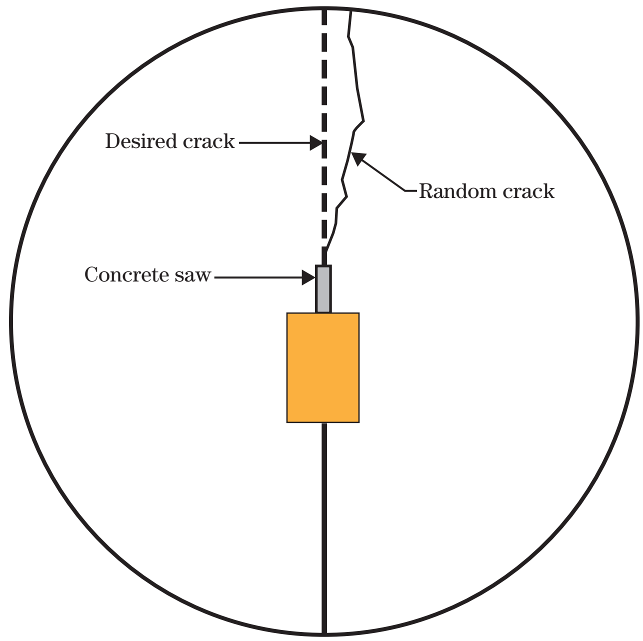
Contraction joints can also be formed in the fresh concrete with groove-forming hand tools or by placing strips of wood, metal, or preformed joint material at the joint locations. These strips can be placed at the bottom or top of a slab or either side of a wall. Grooving tools are generally only effective on thin slabs because a shallow groove is made that will not effectively weaken a thick slab.

Contraction joints should extend to a minimum depth of one-fourth the thickness of the slab or wall. It is recommended that the joint depth not exceed one-third the slab thickness, if load transfer from aggregate

Figure 12–26 (a) Saw cuts made too early and at the proper time and (b) Saw cut made too late



(a)



(b)

Table 12–5 Spacing of concrete contraction joints in feet (PCA)

Slab thickness (inches)	< ¾ inch MSA	> ¾ inch MSA
4	8	10
5	10	13
6	12	15
7	14	18
8	16	20
9	18	23
10	20	25

interlock is important. The joint detail may have to be modified if the contraction joint (sawed, grooved, or formed) could potentially reach the reinforcing steel.

Expansion joints are installed to protect the concrete from damage as it expands from increased temperature. This expansion will damage the concrete when it expands against unyielding objects. For instance, a large unjointed slab can be restrained by friction between the slab and subgrade, restrained by toe-walls in the foundation, or restrained by another structure that it abuts. As the slab expands it will buckle. Properly designed and installed expansion joints consisting of preformed materials allow the concrete to expand into the joint without damage (fig. 12–27). The preformed materials are compressible and many will return to their original thickness as the concrete contracts.

Preformed expansion joint materials may be installed the full thickness of the wall or slab or may be installed along with temporary wood strips or other materials that can be removed to allow a joint sealer to be installed. Chamfer strips are sometimes added to temporary wood strips to form a chamfered edge on each side of the expansion joint at the exposed concrete surface (fig. 12–28). If sealing the joint is not necessary and the preformed expansion joint material is installed the full thickness of the wall or slab, chamfer strips can be installed on each side of the expansion joint material. After the forms and chamfer strips are removed, the excess expansion material can be cut away. Any mortar overlapping the joint material or any fins or wedges of concrete must be removed.

If chamfer strips are not specified, the edge of the concrete on each side of the expansion joint should be tooled with a radius tool or other tool as part of the concrete finishing process. Otherwise, after the concrete sets up, a grinder or carbuandum stone can be used to remove sharp edges.

Figure 12–27 Expansion joints containing preformed expansion joint material

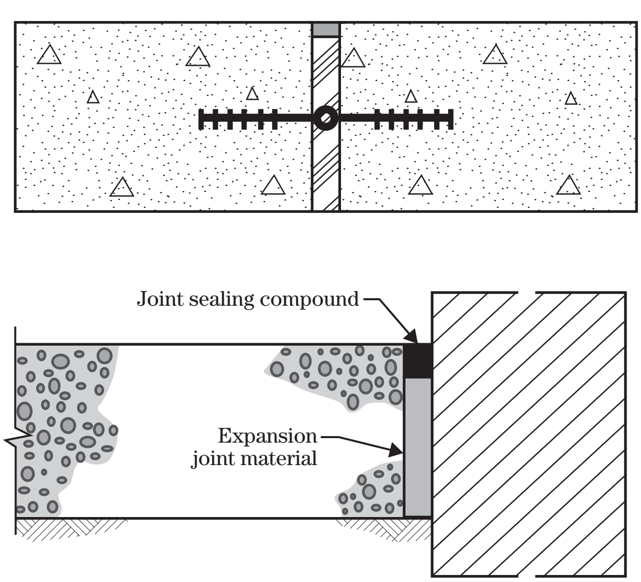
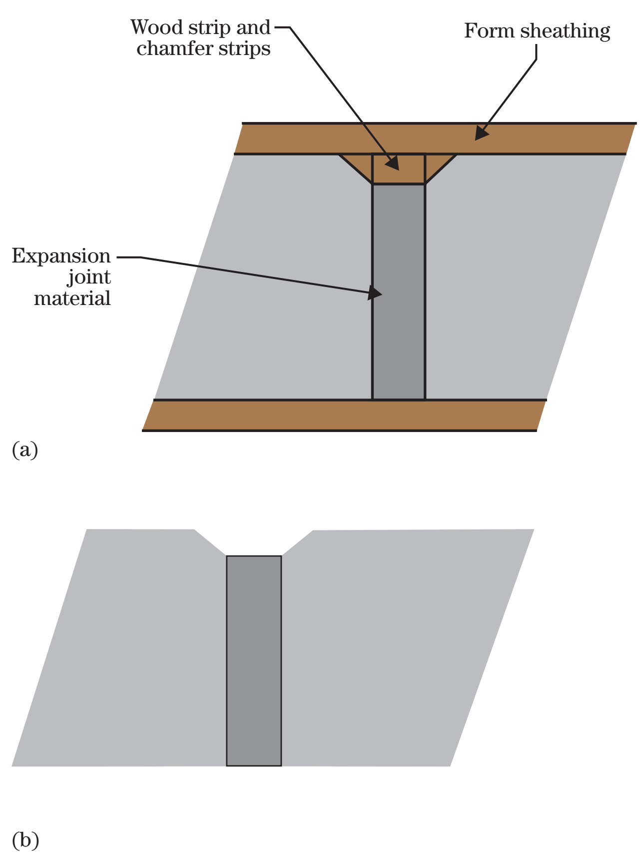


Figure 12–28 (a) Top of formed wall showing temporary wood strip and chamfer strips on each side of an expansion joint. (b) Top of wall after removal of forms.



Reinforcing steel must be terminated on each side of any expansion joint. Steel dowel bars are commonly installed across the joint to resist shear loads that might otherwise cause vertical displacement of the concrete on either side of the joint. The dowel bars are equipped with a plastic cover that slips over one end of the bar and stops before the end of the bar bottoms out inside the cap. The stop allows the bar to be forced further into the cap if necessary when the joint closes as the concrete expands. The half of the bar with the cap on the end is coated with a bond breaker to allow the dowel to move back and forth in the slab without damaging the concrete. Dowel bars must be aligned with the axis of the concrete slab or wall in the direction of movement so that they can move freely as the concrete expands and contracts (fig. 12–29).

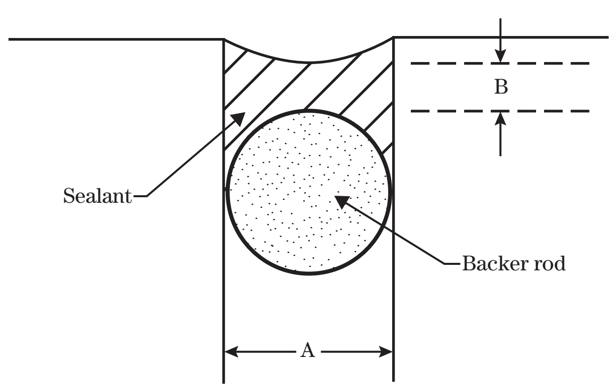
Expansion joints are often sealed to prevent water or other liquid from entering the joint. There are a variety of joint sealants available, each having different characteristics. Some sealants are self-leveling verses those that can be placed in a vertical or sloped joint. There are single- and multi-component sealants and cold- or hot-applied sealants. Some sealants are relatively tough and resistant to puncture while others are susceptible to puncture but are more elastic than the tougher sealants.

Sealants that are commonly specified for NRCS work are described in ASTM C920, Standard Specification for Elastomeric Joint Sealants. Elastomeric means that the sealant is elastic so that it will return to its original shape after being compressed or stretched. ASTM C920 classifies elastomeric sealants by type (type S for single-component, type M for multi-component), by grade (grade P for pourable used on level concrete, grade NS for non-sag used on sloping or vertical concrete), by class number (the number indicating how much the properly installed sealant will stretch in terms of percent of joint width), and by use (T for pedestrian and vehicular traffic, NT for non-traffic areas, I for continuously immersed in liquid, M for use with mortar, A for use with aluminum, and O for substrates other than standard substrates). The inspector must verify that the approved sealant is used.

Proper installation of elastomeric sealants is critical to function. The sealant is applied over a backer rod that is installed before the sealant is applied. The backer rod is a cotton or polymer rope that serves to create a concave shape on the underside of the sealant. A special tool is used to create the same concave shape on the surface of the sealant. The resulting shape of the sealant provides for a relatively thin sealant near the middle of the joint and good surface bonding area where the sealant adheres to each side of the joint (fig. 12–30). The bonding area on each side of the joint must be clean and free of any oil, curing compound, or other substance that may prevent good bond. The backer rod diameter must be such that when installed it is held firmly in place by friction between the rod and the concrete on each side of the joint. The rod must be installed to the proper depth and the joint

Figure 12–29 Dowel bars installed at expansion joint.

Figure 12–30 Joint sealant



Ratio of A: B Should be approximately 2:1

sealer must be tooled to the same concave shape on the exposed surface as the underside of the sealant.

Construction joints are simply joints that are formed whenever concrete placement ceases and is resumed after the in-place concrete sets up. Joints are usually specified on the drawings, but additional unplanned joints may be needed. Unplanned joints should be avoided if possible, but an unplanned construction joint may occur if concrete placement must cease unexpectedly. Any joint where the internal vibrator will not extend into the previously placed concrete should be treated as a construction joint.

Construction joints are never as strong or impermeable as the parent concrete, however, quality construction joints can be strong and not leak. A quality construction joint is obtained by proper preparation and treatment along with good consolidation of the fresh concrete placed against the joint. Adequate preparation may be a simple flushing with water for relatively new concrete or it may require sandblasting old concrete to remove the pitted surface and expose some of the aggregate. The objective in preparing the surface is to create a clean sound surface that will bond well with fresh concrete or a bonding agent.

Adequately cured new concrete that is only a few days old will generally not require the application of a bonding agent. Older concrete will benefit from applying a bonding agent before placing the new concrete against the old concrete. The final step to getting a well bonded, strong, and impermeable construction joint is to consolidate the fresh concrete to ensure the entrapped air is removed from the fresh concrete at the joint.

Before fresh concrete, cement-based bonding mortar or grout is applied to the in-place concrete. The in-place concrete at the joint should be moistened so that water is not absorbed from the fresh concrete. All standing water should be removed from the bonding surface. For non-Portland cement-based bonding agents, such as epoxy or latex, the in-place concrete bonding surface must be dry before applying the agent. For these types of bonding agents, follow manufacturer's recommendations concerning joint preparation.

Epoxy, latex, and other bonding agents have a short window of opportunity in which to mix, apply, and cover with concrete. If set up before the concrete is placed over them, they can become a bond breaker rather than a bond enhancement. This is especially true for latex bonding agents.

One of the best bonding agents is neat-cement grout or a cement-sand grout. A neat-cement grout is composed of Portland cement and water. A cement-sand grout is composed of equal parts sand, Portland cement, and enough water to make a paste. Each grout should contain enough water to attain a creamlike consistency.

There are several reasons Portland cement-based grouts make good bonding agents. They are readily available and economical, have physical and chemical characteristics similar to concrete, and will not become a bond breaker if set up before being covered with concrete.

Neat-cement grout or a cement-sand grout should be scrubbed into the prepared bonding surface with a stiff-bristled brush to fill all of the pits and microscopic voids in the bonding surface. Concrete is then placed against the treated bonding surface before the grout sets up. The layer of grout should not be too thick. A thick layer of grout between the old and new concrete will contain no coarse aggregate to provide resistance to shear loads. To avoid this weak layer, the bonding agent should only be thick enough to fill the pits and voids and not so thick that it embeds any exposed aggregate.

A Portland cement-based bonding agent bonds best if it does not set up before being covered with fresh concrete. One way to avoid this is to include a set retarding additive in the bonding agent. This should always be a consideration when using a Portland cement-based bonding agent in hot weather.

The inspector's responsibilities related to concrete joints include verifying that:

- For contraction joints:
  - — joints are located at specified locations
  - — timing of saw cutting results in a clean cut without raveling at the surface
  - — saw cutting does not occur so late that the concrete cracks ahead of the saw
  - — contraction joints extend to a depth of one-fourth the slab thickness

— contraction joints extend to a depth less than one-third the slab thickness if load transfer from aggregate interlock is important

- For expansion joints:
  - — joints are located at specified locations
  - — expansion joint material is installed as shown on the drawings
  - — expansion joint material is held firmly in place
  - — chamfer strips are installed if specified
  - — when chamfer strips are not installed the edge is formed or ground so that it is not sharp and prone to chipping
  - — any mortar overlapping the joint material or any fins or wedges of concrete are removed
  - — reinforcing steel terminates on each side of the expansion joint
  - — dowel bars, when specified, are placed at the depth and location shown on the drawings
  - — dowel bars are aligned with the axis of the structure
  - — caps are placed on one end of each dowel bar
  - — a bond breaker is applied to the capped end of each dowel bar
  - — joint sealants, when specified, are of the type specified
  - — the backer rod is the proper diameter
  - — the backer rod is installed to the proper depth
  - — the sealant bonding surface is clean and free of bond breaking substances
  - — the sealant is tooled to the required concave shape
- For construction joints:
  - — joints are located at specified locations where applicable
  - — joints are cured until covered with subsequent concrete or bonding agent
  - — joints are prepared for bonding as specified
  - — where a bonding agent is required, the bonding agent complies with specifications
  - — where a bonding agent is required, the bonding agent is not too thick
  - — where a Portland cement based grout is used for a bonding agent, the grout is scrubbed into the surface of the existing concrete
  - — concrete placed against the joint is adequately consolidated

(m) Waterstops

Waterstops are installed where a leak free joint is required. The joint may be any of the three types: contraction, expansion, or construction. Figure 12–31 shows an expansion joint containing a waterstop, joint filler, dowel bar, backer rod, and joint sealer. Waterstop materials are normally plastics or bentonite tape, but can also be metal. Warning, bentonite tape placed too close to the face of the concrete can cause spalling.

Install a waterstop securely so that it remains in place during concrete placement. Figure 12–32 shows one method of securing a waterstop. The waterstop should be centered with equal halves on each side of the center of the joint and be located in the center of the wall or slab unless otherwise shown on the drawings. Waterstops used at expansion joints generally contain a bulb or fold in the middle of the waterstop that must be centered in the center of the joint.

At corners the waterstop should be cut and welded rather than bent. Otherwise it is near impossible to bend the waterstop to a 90 degree angle (fig. 12–33). Premolded corner pieces made from the same waterstop materials can be purchased or fabricated in the field. Premolded tees can also be purchased or field fabricated (fig. 12–34).

Plastic waterstops can be solvent bonded or heat welded. Care must be taken to attain a good bond without reducing its cross section and thereby weaken the waterstop.

Waterstops must be clean and free of form oil or any substance that would prevent good bond to the concrete. The inspector should check waterstops prior

Figure 12–31 Joint sealant

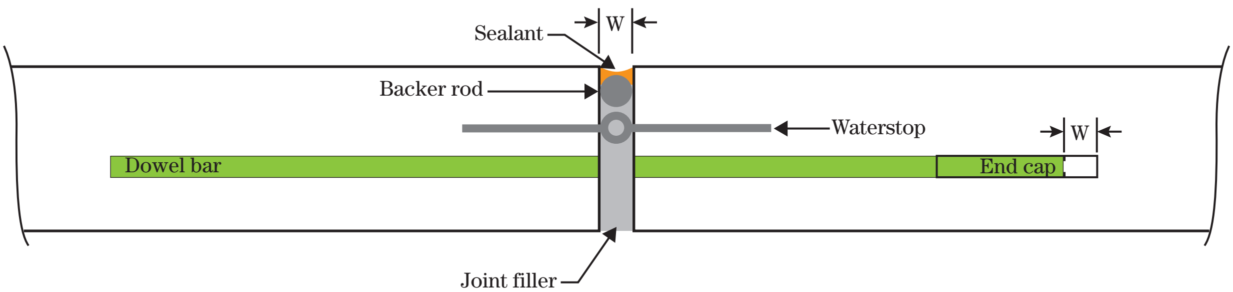


Figure 12–32 Expansion joint showing a waterstop, joint filler, dowel bar, backer rod, and sealant

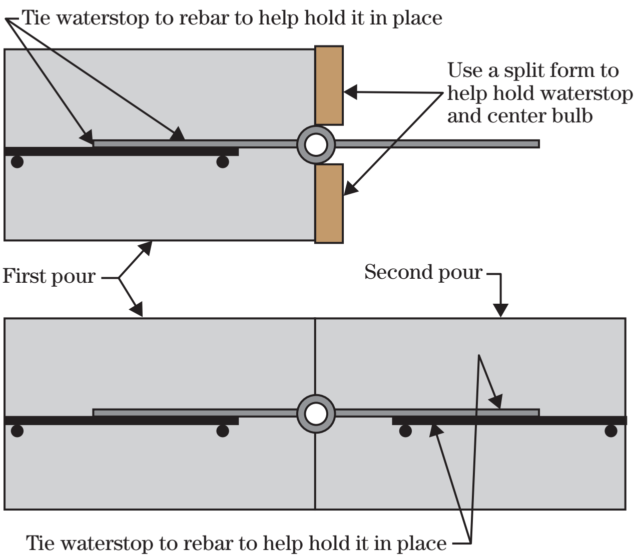


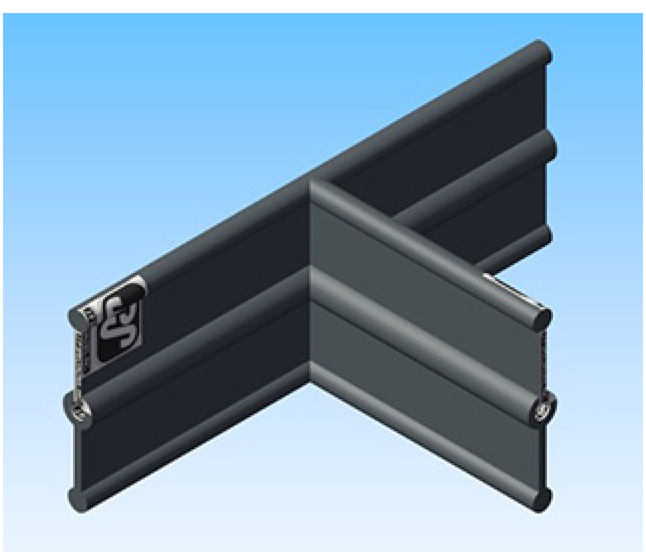
Figure 12–33 Securing a waterstop during construction

to concrete placement to verify they are clean, held securely in place, and are not damaged.

The inspector's responsibilities related to waterstops include verifying that:

- the specified waterstop is installed
- bentonite waterstops are not installed near the face of the concrete
- bentonite waterstops are kept dry until completely covered with concrete
- the waterstop bulb is centered in the joint
- waterstops are centered in the slab or wall or located as otherwise specified
- corners and tees are fully welded
- premolded corners and tees are used to aid in keeping the waterstop in position
- welds are well bonded and do not weaken the waterstop
- waterstops are secured in place and do not move during concrete placement
- waterstops are clean and not damaged during concrete placement

Figure 12–34 Premolded waterstop tee



(n) Removal of forms, supports, and protective coverings

Forms should be removed as soon as specifications allow so that any necessary repairs or surface treatments can be made while the concrete is still green and conditions are most favorable for a good bond if patching is required. Forms must be removed carefully to avoid damaging the concrete. There should be no measurable deflection or distortion of the concrete during the removal of supporting forms.

Forms can be used for initial curing, but do not provide for the best curing especially when it is hot and dry. Forms in arid climates should be kept wet and removed to begin finishing and curing as soon as practical.

In cold weather it may be necessary to keep the forms and protective coverings in place to help insulate the concrete. Insulated forms are sometimes used in cold weather. There is potential for *thermal shock* when forms are removed during cold weather. This rapid cooling of the concrete surface can cause thermal cracking. It may be possible to loosen the forms to provide a thin space between the concrete surface and the form sheathing to avoid thermal shock. Maintaining this thin space for a few hours will allow the concrete to cool more slowly in an effort to avoid thermal shock. Also, leaving the forms in place for a longer period will allow the concrete to gain strength and cool slowly, but wooden forms must be kept moist to prevent wicking moisture from the concrete.

Supporting forms are those that must be left in place long enough for the concrete to gain sufficient strength to support itself and any surcharge. Generally, supporting forms for concrete that must only support itself can be removed when the concrete attains 70 percent of its specified 28 day strength. The designer may specify the strength needed before form removal. The strength can be monitored by testing concrete specimens (cylinders) that are cured adjacent to and under the same conditions as the concrete in question.

As an alternative to testing the concrete strength to determine when forms can be removed, specifications may allow the forms to be removed at a specific time after the concrete has been placed. The concrete will not gain sufficient strength if the air next to the concrete is so cool that it significantly slows the cement hydration. Generally the amount of time that must pass before removing forms must be extended by one day for each day the air temperature is 50 degrees Fahrenheit or less. Construction Specification 31 provides accumulated form removal times for various types of concrete members.

The inspector's responsibilities related to the removal of forms, supports, and protective coverings include verifying that:

- forms are carefully removed as soon as specifications allow
- there is no measurable deflection or distortion of the concrete when removing supporting forms
- forms left on for curing are kept moist
- in cold weather, forms are removed in a manner to avoid thermal shock
- supporting forms are kept in place for the specified length of time

(o) Finishing formed surfaces

The inspector should take a close look at the surface of formed concrete as soon as the forms are removed. Look for bulging concrete or honeycombed areas that must be repaired. Verify that the surface meets the specified tolerances for line and grade or meets industry tolerances when not specified. Appendix E contains typical industry tolerances for concrete work.

The contractor should repair any defects and fill all form tie holes as soon as possible. All form fins or burrs should be ground off and the surface finished as specified. The specification may require no further finishing. If further finishing is specified, the specification will likely require the surface be rubbed with a carburandum stone or coated with a coating specially formulated for concrete.

Concrete that is finished by stone rubbing should be rubbed as soon as the forms are removed as it is easier to remove fins, burrs, and other irregularities before concrete gains significant strength. *Bug holes* which are formed by air bubbles entrapped against the forms may be filled with a sand-cement mortar. The mortar can be applied during the rubbing process by troweling it on the surface just ahead of the stone rubbing. The contractor should not be allowed to apply a thick mortar or paste on the surface in lieu of stone rubbing as thick coatings tend to debond or otherwise deteriorate.

If the concrete is coated with an approved proprietary product, manufacturer application instructions must be strictly followed. These products have a shelf life and must not be used after the expiration date listed on the container. Mixing water for coatings must meet the same requirements as for the concrete. The product and the color should be approved by the responsible engineer. Additionally, bonding agents are sold to be used with some coatings. The bonding agent is generally applied to the surface just prior to applying the coating and for some products may be mixed directly with the coating prior to application. Coatings can only be applied after the specified curing period unless the coating is also a curing compound. Curing compounds must be completely removed prior to coating or the curing compound used must be non-wax based and formulated to be used for bonding surfaces.

The inspector's responsibilities related to finishing formed surfaces include verifying that:

- line and grade are within specified or acceptable tolerances
- defects are repaired and tie holes are filled ASAP
- all form fins or burrs are ground off
- surface is finished as specified by rubbing or coating
- bug holes are filled with mortar prior to rubbing or coating
- coatings are of the type and color approved by the engineer
- the expiration date on the coating container is beyond the application date
- the mixing water meets the same requirements as the concrete
- bonding agents are used with coatings as applicable
- coating and bonding agents are applied according to manufacturer's instructions

- curing compound is completely removed prior to applying bonding agents/coatings or curing compound is formulated for bonding surfaces

(p) Finishing unformed surfaces

Unformed surfaces refers to flatwork or slabs. Other unformed surfaces may be surfaces that are formed in the earth, but these will generally not be exposed and not require finishing.

As concrete is being deposited and consolidated it must also be screeded to grade. A screed may be a length of wood as is common on narrow flatwork such as sidewalks and driveways or ramps. A screed may also be a power screed containing a vibrating mechanism to help slump the surface to make it easier to spread. The screed knocks the piled concrete down to grade.

After screeding and before any bleedwater appears on the surface, a bull float or darby is applied to help embed aggregates just below the surface, cut off minor peaks, and bring the surface closer to the specified grade. The floated surface should have a finish that has no irregularities exceeding a quarter inch in 10 feet; this can be checked with a 10-foot-long straight edge. For many jobs, there may not be a need to do any more surface finishing. But if a smoother and harder finish is desired, or if the surface will be textured, finishing must continue after all of the bleedwater is gone.

Floats are made from plastic, wood, or magnesium. Magnesium floats are essential for air-entrained concrete because it will not stick to air-entrained concrete. Air-entrained concrete tends to stick to wood, plastic, or other metal which will cause the concrete surface to tear.

After floating or darbying, the concrete must rest until all of the bleedwater and attendant surface sheen disappears. This may occur fairly quickly depending on the amount of water in the mixture, the ability of the concrete to bleed downward as well as upward, and the ambient conditions at the time of finishing. In cold damp weather it may take several hours for all of the bleedwater to disappear; finishers may impatiently resume the finishing process before all of the bleedwater is gone. Doing so will cause bleedwater to become trapped under the surface and eventually result in spalling of the thin mortar layer above the entrapped bleed water. Also, finishing the surface while bleedwater is coming to the surface will result in a weak surface with a high water to cement ratio.

In hot, arid, or windy weather it may be difficult to determine when the bleedwater ceases because the bleedwater may quickly evaporate. One way to determine if bleedwater is still coming to the surface is to place a piece of wax coated paper or other opaque non-absorptive material on the concrete surface and periodically check to see if bleedwater has collected under it. The material must be shaded to limit the effect of solar heat on the material that could lead to a false reading. Wipe away any bleedwater and return the material to the surface until, when lifted, no bleedwater is observed between the concrete and the material.

Finishing can resume after all of the bleedwater is gone. When the surface can sustain foot pressure with only about a quarter inch indention all exposed edges including expansion joint edges can be compacted and shaped with a radius tool. This will make the edge stronger and less prone to chipping. Expansion joints can be formed with a jointing tool or by saw cutting. Surface texturing can be done by stamping groves or other depressions in the concrete.

For smooth dense impact resistant surfaces, such as those used for industrial floors, troweling can continue after all of the bleedwater is gone. This troweling operation is done by repeatedly applying increasing pressure to the surface to compact the surface. Whether done by hand or by machine, the angle of the trowel blade to the concrete surface is continually increased until the blade edge bears all of the force applied by the trowel to create a dense surface. This type of surface is not normally needed for most slabs and is not recommended for outdoor concrete as it tends to remove entrained air from the concrete surface. It will also result in a surface that will be slick when wet.

Concrete finishers may want to spray water on the concrete surface to aid in finishing. This should never be allowed as it will increase the w/c of the surface concrete making it weak and less durable. Spreading dry cement on the surface to absorb water or repair imperfections should never be allowed as this will result in *dusting*, *crazing*, and mortar flaking.

Keeping the concrete from drying out during finishing is difficult because neither curing compound nor water can be added before the finishing is completed. If the initial floating operation provides an adequate surface finish, wet curing can begin before the bleedwater appears on the surface. Otherwise, curing should begin immediately after all of the finishing operations have been completed.

The inspector's responsibilities related to finishing unformed surfaces include verifying that:

- grade is within specified or acceptable tolerances
- only magnesium floats are used for air-entrained concrete
- after floating or darbying no finishing operation occurs while bleed water is coming to the surface
- the surface is finished as specified
- curing begins immediately after finishing

(q) Curing

The object of curing is to prevent the loss of moisture from the concrete mixture during its early life when most of the cement hydration occurs. If the concrete's internal relative humidity drops below 80 percent, the paste can dry out to a level where cement hydration stops. Evaporation, absorption by dry forms, and bleeding or wicking into the foundation can rob the concrete of water needed for hydration.

The first seven days after the concrete is placed is the critical period for keeping the moisture for hydration in the concrete. Curing with clean water is the best way to keep the internal relative humidity above 80 percent. Membrane curing compounds, while not as good as wet curing, will aid in preventing the concrete from drying out to the point where cement hydration ceases.

If curing is interrupted during the seven day curing period, the curing period should be extended an amount equal to the interruption period to allow for a full seven days of curing. Curing may be interrupted during the removal of forms or for some unforeseen reason, such as an interruption in the supply of water used for curing. When the concrete temperature falls below 50 degrees Fahrenheit cement hydration slows considerably. For this reason, if the concrete temperature drops below 50 degrees Fahrenheit during the seven day curing period, the curing period should be extended so that the concrete has a chance to cure for a full seven days at or above 50 degrees Fahrenheit.

Care must be taken when the concrete first sets up to not damage the concrete. Spraying the concrete can erode the surface and, if setting on the concrete surface, agitating pumps used for applying curing compound can damage the surface when the concrete is young.

Wet curing by a continuous supply of water may not be practical. It is accepted practice to cover the concrete with burlap or other absorptive material that is kept wet. New burlap will stain the concrete and should not be used unless staining can be tolerated. Plastic and wax coated curing paper may also be used to cover the concrete directly or to cover wet burlap. Soaker hoses under a plastic cover can be effective at keeping the surface wet. When concrete is covered directly by curing paper or plastic, the paper must be continuously held in intimate contact with the concrete surface to prevent the flow of air between the covering and the concrete.

Supplemental heat used to keep the concrete warm in cold weather can cause rapid drying of the air near the concrete. Using steam to supply heat under a tented area above the concrete is an excellent way of preventing drying.

Curing compounds are often used in lieu of or in addition to wet curing. There are various types and classes of curing compounds. The instructions to Construction Specification 31 contains table (table A–31) listing the various curing compound designations along with a description and short explanation of their usage. If the concrete is to be painted or stained or if there will be additional surface treatment of the concrete after the curing period, verify that the curing compound used is compatible with the planned treatment. If the surface being cured will be a bonding surface to other concrete, the curing compound may interfere with bonding. It is always advisable to confer with the curing compound supplier or manufacturer if the use of the product is questionable for any application.

Since curing compounds contain solids suspended in liquid they must be agitated before application and continuously agitated during application. A continuously recirculating pressure sprayer operating at an application pressure of 75 to 100 pounds is desirable (fig. 12–35). Manual hand pump sprayers should not be allowed for areas exceeding 400 square feet as their application rate is generally not adequate to completely cover all of the surface before the surface begins to dry out. For small surface areas of 400 square feet or less, a soft-bristled brush, paint roller, or hand sprayer may be used.

Curing compounds should be delivered to the worksite in their original container that carries the manufacturer's name and the brand name. Compounds must be protected against freezing if they are water emulsions. Type 1–D compounds must be agitated before application to thoroughly mix in the fugitive dye which may have settled to the bottom of the container. Adherence to the curing compound manufacturer's label is imperative.

The application rate for curing compound is generally one gallon per 200 square feet. At this rate the membrane will be thin. The membrane should be uniform in color if the compound is continuously agitated during placement. Otherwise it may appear white in some areas to translucent in others

Figure 12–35 Continuously recirculating pressure sprayer *(courtesy of the Chas. E. Phipps Company)*

The inspector's responsibilities related to curing concrete include verifying that:

- curing begins as soon as practicle after the concrete is finished
- immediately after placement, the concrete is cured for seven days or for the specified length of time at a concrete temperature at or above 50 degrees Fahrenheit
- the curing period is extended if the concrete temperature drops below 50 degrees Fahrenheit or is otherwise interrupted in order to cure the concrete for the specified amount of time
- care is taken not to damage the concrete during the curing process
- new burlap is not used if staining of the concrete cannot be tolerated
- coverings such as burlap, plastic, or curing paper are kept in intimate contact with the concrete surface
- coverings over soaker hoses are anchored with the edges firmly pressed against the concrete to limit air movement between the covering and the concrete
- when applicable, only the specified and approved type and class curing compound is used
- curing compound is applied with a continuously agitating sprayer
- manual hand pump sprayers, brushes, or paint rollers are not used on large areas over 400 square feet
- timely uniform curing compound coverage is attained
- any curing compound that gets on a bonding surface is removed prior to bonding with subsequently placed concrete or coatings

(r) Concrete patching, repair, and replacement

New concrete is weak and susceptible to damage that must be repaired. There may be honeycomb in formed concrete that requires patching or repair, and tie cone holes should be patched. It is best to patch and repair new concrete as soon as possible because new concrete bonds better with the repair or patching material than does older concrete.

Old concrete may require rehabilitation to extend its life and restore it to a serviceable condition. Sometimes, depending on the condition of the concrete and reinforcement, it is more economical to replace the concrete. In some instances partial replacement and repair of the remaining concrete may be in order.

Regardless of whether the concrete needing repair is new or old, the first priority in any repair is to investigate the problem to determine the cause of the deficiency and develop a repair plan. The investigation may simply require looking at the concrete or there may be a need to remove some of the concrete until the extent of the deficiency can be determined. The plan should address:

- the extent of removal
- removal technique
- the geometry of the removal and repair area or cavity
- repair and replacement of reinforcement steel
- bonding surface preparation
- any bond enhancement such as a bonding agent
- the concrete mix or repair material to be used to fill the cavity
- placement technique
- filling any cracks from shrinkage
- finish of the repaired concrete
- curing and protection of the repaired concrete

When the repair is necessary because of fault of the contractor, the contractor should submit the repair plan. The responsible engineer should concur in or recommend revising the contractor's repair plan before implementing the plan.

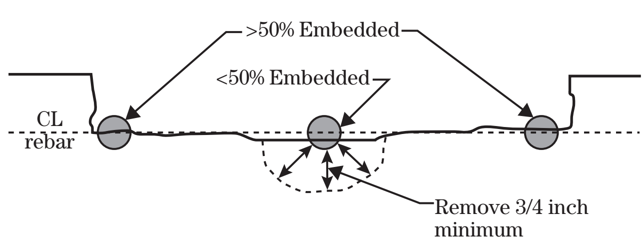
Any damaged or deficient concrete must be removed. For new concrete this may mean removing honeycombed or segregated concrete. Concrete should be removed beyond the limits of the deficient concrete so that only good quality concrete remains.

If reinforcing steel is exposed with less than 50 percent of any rebar section exposed, there is no need to remove concrete beyond the steel. Conversely, if more than 50 percent of the cross section of bars is exposed, the concrete should be removed to a depth of three-quarter inch behind the steel (fig. 12–36).

Various methods of removal are available including sawing, grinding, sandblasting, shotblasting, air chisel, chipping hammer, jackhammer, hydro jet, scabbler, and scarifier or planer. Care must be taken to not damage the concrete that is to remain in place. High impact demolition tools such as jackhammers can loosen the bond between steel and concrete or crack or otherwise damage concrete that is to be left in place. For this reason high impact demolition equipment should not be used unless approved by the responsible engineer.

The geometry of the cavity remaining after the deficient concrete is removed is important. The cavity must not contain any space the concrete mix cannot fill. Any space too small for the large aggregate in the concrete repair mix to enter must be enlarged so that the mix can fill the entire cavity. The cavity wall should intersect with the concrete surface at an approximate 90 degree angle to avoid a feather edge (fig. 12–37). This can be accomplished by cutting the perimeter of the repair cavity with a concrete saw. The depth of the perimeter cut is dependent on the maximum aggre-

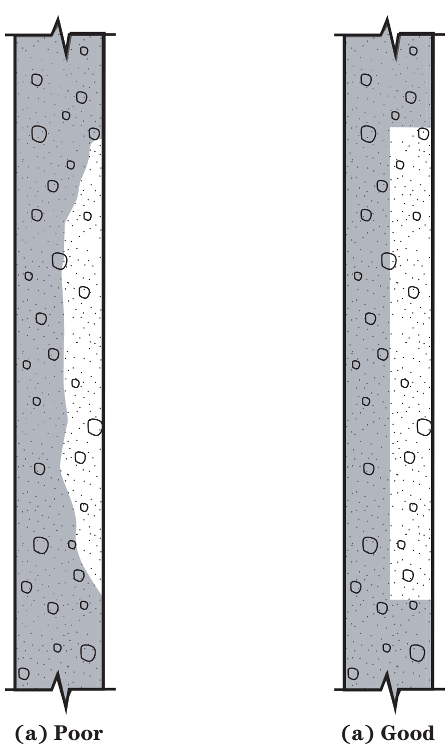
Figure 12–36 Preparing concrete for repair with less than 50% of the rebar section exposed and with greater than 50% of the rebar section exposed



gate size in the repair material. Generally the repair material will have a small maximum aggregate size of approximately half of an inch and a cut depth of three-quarters inch will be sufficient to allow the repair material to fill the entire space including that at the perimeter of the cavity.

Rebar containing heavy rust should be sand blasted or wire brushed to remove any scaling rust. If the rebar still has over 75 percent of its original section after all rust is removed it can remain in place without splicing. Rebar that has lost more than 25 percent of its original cross section must be replaced or repaired. It can be repaired by splicing another piece of rebar of the same grade and size onto the portion of the bar being repaired. The splice must extend beyond each side of the repaired portion for a distance equal to the bar lap splice length. Unless otherwise specified, a minimum splice length of 30d or 30 times the diameter of the bar is generally sufficient.

Figure 12–37 (a) Poor cavity geometry verses (b) good cavity geometry



New concrete that is only a few days old will generally bond well with repair concrete without the use of a bond enhancement. For old concrete a bond enhancement may be needed. Bond enhancements (bonding agents) can be epoxy based, latex based, or Portland cement based. The bonding agent should be brushed into the bonding surface with a stiff bristle brush so that it fills any pits and micro cavities. The repair concrete should immediately cover the bonding agent to prevent the bonding agent from setting up prior to being covered with the repair material. Bonding agents made from Portland cement and water or Portland cement, water, and fine sand are good for bonding concrete. In addition, Portland cement bonding agents will not reduce bond strength if set up before being covered with concrete. Latex bonding agents are good as long as they are still fresh when covered with concrete, but if they dry out or set before being covered with concrete they become bond breakers rather than bond enhancement.

The concrete mix used to fill any repair cavity must have properties such as *modulus of elasticity* and *coefficient of thermal expansion* similar to the concrete being repaired. Because Portland cement concrete has the same properties as the concrete being repaired, it is an excellent choice for concrete repair. For relatively small cavities the maximum aggregate size should be small. A good rule of thumb is to limit the maximum aggregate size to a third of the thickness of the repair. As with any Portland cement concrete, keeping the water to cement ratio low (0.40 or less) is absolutely necessary to provide a strong impermeable repair concrete with low shrinkage potential. Air entrainment should also be added to protect against freeze/thaw damage where applicable. Five to seven percent air content is recommended for concrete with a maximum aggregate size of three-quarters of an inch. A superplasticizer is used to increase the workability of the repair concrete while keeping the water to cement ratio low.

There are several products on the market other than Portland cement concrete for repairing concrete. Many of these are readily available at building supply stores and are very user friendly. Epoxy-modified concrete and latex-modified concrete are made by adding an epoxy or latex additive to the Portland cement concrete. The additives improve concrete bond and strength when properly used. Epoxy concrete contains no Portland cement; it contains an epoxy binder with coarse and fine aggregate. Strict adherence to manufacturer's installation instructions including bonding surface preparation and curing is critical to the success of these products.

A dry pack mortar made from sand, Portland cement, and water is one of the best repair materials for filling small cavities such as form tie cone holes. Larger cavities can also be filled with dry pack mortar; it should be installed in layers approximately a half inch thick. Dry pack mortar is made with one part cement, two to two and a half parts fine sand (passing the No 16 sieve), and just enough water to form a ball. The mortar is compacted into the cavity by a hammer and wooden stick. This will force the mortar into any pits or micro cavities which will enhance bond. For old concrete, a bonding agent such as *neat-cement grout* brushed into the surface just before installing the dry pack mortar will likely enhance bond. For dry pack mortar with a low water to cement ratio, curing is critical.

Where concrete is to be placed into a cavity, forming will be required and must include a port or opening through which to convey the repair concrete. This can be problematic if a bond enhancement is to be used because the form would have to be installed and secured after the bond enhancement is brushed into the bonding surface. When relatively new concrete is being repaired a bonding enhancement is generally not needed.

All repair products containing Portland cement must be cured for the specified curing period.

The inspector's responsibilities related to concrete patching, repair, and replacement include verifying that:

- new concrete is repaired as soon as possible
- concrete needing repair is fully investigated to determine the extent of the area needing repair
- the contractor's repair plan as submitted or revised is concurred in by the responsible engineer
- all damaged concrete is removed
- if more than 50 percent of the reinforcing steel is exposed after concrete removal, the concrete is removed to a depth of at least three-quarters inch behind the steel
- only approved methods are implemented when removing concrete
- concrete removal methods do not damage the portion of the structure that is to remain in place
- high-impact demolition equipment is not used to remove concrete unless approved by the responsible engineer
- the repair cavity geometry complies with standards of best practice
- rebar that has lost more than 25 percent of its original cross section is replaced or repaired
- rebar is replaced or spliced with rebar of the same grade and size as that being spliced or replaced
- rebar laps and splices are of the specified length
- bonding surfaces are prepared as specified
- bond enhancements are of the type and quality specified or otherwise approved
- bonding agents are brushed into the bonding surface
- bonding agents are covered before they set
- safety concerns associated with repair products such as epoxies are addressed
- the repair concrete mix has properties similar to the concrete being repaired
- the repair concrete mix is approved by the responsible engineer
- the repair concrete quality is verified, where applicable, by batch ticket and tests for air content, slump, and temperature
- when specified, compressive strength specimens (cylinders) are made from a representative sample of the repair concrete
- repair materials are cured as specified or recommended by the repair material manufacturer

(s) Concreting in cold weather

In concrete work, cold weather is defined as a period when, for more than 3 consecutive days, the following conditions exist:

- the air temperature is not greater than 50 degrees Fahrenheit for more than one-half of any 24-hour period
- the average daily air temperature is less than 40 degrees Fahrenheit. The average daily temperature is the average of the highest and lowest temperatures occurring during the period from midnight to midnight.

Special measures are required for concrete placement in cold weather. Concrete gains strength slowly when temperatures are below 40 degrees Fahrenheit. Serious damage can result when concrete freezes and thaws at an early age. Concrete of good quality can be placed throughout the winter if protection is provided when temperatures of 40 degrees Fahrenheit or lower occur during the placing, protection, and curing periods. Materials for enclosures, insulation, heating equipment, fuels, and other incidentals must be available at the site before the work starts. Concrete must not be placed on a frozen subgrade. All snow and ice must be completely removed from forms, the subgrade, reinforcing steel, and other materials.

A cold weather concrete plan must be provided by the contractor. The contractor and responsible engineer should concur in the plan. Included in the plan should be the means and measures to protect the concrete from freezing and thermal shock during the concrete installation and specified protection period. The plan should address how the concrete temperatures will be monitored to document specification compliance. It should also address how the concrete will be cured as proper curing is especially critical during cold weather. All of the systems and materials required by the plan to maintain concrete temperature and provide protection and continuous curing must be in place before concrete is ordered.

Concrete freezing at an early age must be avoided. From the time concrete is placed until it attains a compressive strength of 500 pounds per square inch it contains water that can freeze and expand to damage the concrete. After the concrete attains a strength of 500 pounds per square inch, the water that can freeze and damage a relatively low water to cement ratio mix has been consumed by cement hydration and removed by bleeding. Most concrete at 50 degrees Fahrenheit or greater will attain a compressive strength of 500 pounds per square inch within 24 hours. Thus, the greatest risk of damage from freezing occurs within the first 24 hours. Anytime there is a potential for freezing, concrete should be protected to prevent any part of the structure from freezing during the first 24 hours. Concrete should be maintained at or above 50 degrees Fahrenheit during the protection period.

Concrete must be cured and maintained above a specified minimum temperature or the minimum temperature given in table 12–6 for a minimum of 3 days after placement. A longer curing period is better. Construction Specification 31 requires the concrete be cured a minimum of seven days.

Concrete flatwork that is kept saturated by melting snow or other water source will continue to retain water that is subject to freezing. Saturated concrete is at risk of damage from freezing until it attains a compressive strength of 3,500 pounds per square inch. Concrete that will be subject to these conditions should be air entrained, have a relatively low water to cement ratio, and be protected from freezing until it attains a compressive strength of 3,500 pounds per square inch. Several compressive strength specimens (cylinders) can be placed in the same environment as the concrete and tested to estimate the in-place concrete compressive strength.

Increasing concrete mix temperature by adding accelerating admixtures or high early strength cement, such as Type III Portland cement, will increase the rate of strength gain. Table 12–6 lists recommended minimum concrete temperatures when concrete is placed and for three days after placement. When placing concrete in cold weather, starting with a mix containing an accelerating admixture, a high early strength cement, or both is generally best. Calcium chloride is commonly used as an accelerating admixture in non reinforced concrete because it is inexpensive. It should be limited

Table 12–6 Recommended minimum concrete temperatures as placed and maintained for a minimum of three days after placement

Section size, minimum dimension in inches			
< 12	**12 – 36**	**– 72**	**> 72**
55 °F	50 °F	45 °F	40 °F

to a dosage of 2 percent or less by mass of cement in the mix. It should not be used for steel reinforced concrete because it will accelerate steel corrosion. Non chloride accelerating admixtures can be used for steel reinforced concrete. Construction Specification 31 does not allow calcium chloride to be used unless otherwise specified in the items of work and construction details.

Concrete mix temperature can generally be increased a sufficient amount by heating the mixing water if air temperatures are consistently at or above 25 degrees Fahrenheit. When the air is below this temperature, heating the aggregates may be required. If the mixing water is above 140 degrees Fahrenheit or the aggregate is above 150 degrees Fahrenheit, there is a potential for flash set. Flash set is a quick setting of a portion of the cement which results in cement balls in the mix. Concrete containing cement balls will be weaker and less durable than the same mix without cement balls.

Concrete should never be placed on frozen subgrade or forms that are 32 degrees Fahrenheit or colder. This will cause early freezing and may seriously prolong setting of the concrete. Ordinarily, the temperatures of contact surfaces, including subgrade materials, need not be higher than 35 degrees Fahrenheit. When concrete is being placed under cold weather conditions, it is recommended that the temperature of contact surfaces not be more than 10 degrees Fahrenheit above the minimum recommended placement temperature given in table 12–6.

There are a couple of options that may allow successful placement of concrete when the subgrade is frozen. One option is to add an extra inch or two of concrete on the frozen subgrade as a sacrificial layer to protect the remaining concrete from freezing. The other option is to place insulating material between the subgrade and concrete. For either option there may be problems caused by subgrade settling after the subgrade thaws. The potential for settlement of frozen subgrade depends on the type of soil. Generally, clays and silts are more prone to settlement after thawing than granular gravels and sands. Before placement of concrete is allowed over frozen subgrade, tests should be conducted to verify settlement potential and the design engineer consulted to determine if the potential settlement is acceptable.

As shown in table 12–6, the minimum concrete placement temperature is dependent on the thickness of the concrete being placed. The temperature must be higher for thin sections than for thicker concrete members to retain enough heat to attain a compressive strength of 500 pounds per square inch in 24 hours. Concrete temperatures that are much higher than those shown do not result in a proportionally longer protection against freezing. Higher concrete temperatures require more mixing water, increase the rate of slump loss, may cause quick setting, and increase the potential for cracking because of thermal contraction. For cold weather concreting, placement temperatures should not exceed the minimum temperatures shown in table 12–6 by more than 20 degrees Fahrenheit.

Maximum/minimum thermometers (fig. 12–38) are commonly used to monitor concrete temperature. A max/min thermometer can be placed on the concrete surface and covered with an insulating blanket to attain a fairly accurate reading of the daily maximum and minimum temperature of the concrete surface. A simple way to monitor the internal temperature is to form a well or several wells in the concrete into which a pocket thermometer can be inserted. The pocket

Figure 12–38 Max/min thermometer

thermometer or a nail of the same or slightly larger diameter than the thermometer probe can be inserted momentarily to create a well or several wells at inconspicuous locations before the concrete has hardened. After the concrete hardens the thermometer can be inserted at any time. These wells can be filled with mortar after they are no longer needed.

Pocket thermometers (fig. 12–39) such as those with dials or digital readouts are typically used to verify concrete temperature. The accuracy of pocket thermometers will vary from time to time and from one thermometer to the next. Thermometer accuracy should be verified prior to use and occasionally throughout the use period. A simple way to verify the accuracy of a pocket thermometer is to place it next to a thermometer known to be accurate. Also, a thermometer placed in ice water should read near 32 degrees Fahrenheit plus or minus 1 degree Fahrenheit.

Concrete will be cooler at edges and in thinner parts of the structure. The concrete temperature should be monitored in these cooler areas when the purpose of measuring the temperature is to verify that the concrete is being maintained above a specified minimum temperature. If the concrete temperature is being monitored to assess the potential for thermal shock,

Figure 12–39 Pocket thermometer (courtesy of Gilson Company Inc.)

which can occur after the concrete protection is removed, the temperature of the warmest portion of the concrete away from thin sections and edges should be monitored.

Insulation is often used to maintain concrete temperature during the protection period. The minimum temperatures shown in table 12–6 should be maintained for a protection period of at least three days after placement. As with any chemical reaction, cement hydration produces heat. Most of the heat is produced in the first three days after the concrete is mixed. Adequate insulation may be all that is needed to maintain the concrete temperature to meet specification requirements or those listed in table 12–6. Be aware that too much insulation can result in high concrete temperatures that can cause thermal cracking or increase the potential for thermal shock.

For concrete that will be partially or fully loaded soon after the protection period, the protection period may need to be extended beyond 3 days. The necessary length of the protection period will depend on the cement type and amount, whether accelerating admixtures were used, the adequacy of the curing effort, and the loads that must be carried. The protection period should be extended to allow the concrete to gain sufficient strength to support the anticipated loads. The design engineer should be consulted to determine the minimum strength needed to support the loads.

Enclosures made from wood, canvas, or plastic sheeting are effective for protecting concrete and workers during cold weather. Plastic enclosures that permit sunlight are popular, but may be expensive to heat if supplemental heating is needed.

There are three types of heaters commonly used to provide supplemental heat to concrete enclosures: direct fired, indirect fired, and hydronic systems. Direct fired systems are heaters that have an exhaust that is not vented to the outside of the enclosure. Carbon dioxide in the exhaust will adversely react and weaken the surface of concrete. The surface will be chalky if it has suffered prolonged exposure to carbon dioxide (fig. 12–40). Additionally, carbon dioxide saturated air is dangerous to breathe. Indirect fired heaters are vented to the outside of the enclosure. Hydronic systems transfer heat by circulating a heated glycol/water solution in a closed system of pipes or hoses. The hoses can be used to heat the subgrade, they can be embedded in the concrete, or they can be placed above or near the concrete in an enclosure or under insulation to heat the air near the concrete.

Because heaters tend to dry the air within an enclosed space, it is important to protect the concrete from drying. Using steam to heat an enclosure is a very desirable practice. Otherwise, continuous wet curing or complete coverage of an approved curing compound is imperative for concrete in a heated enclosure.

Thermal shock can occur with sudden cooling of the concrete surface while the interior is still warm resulting in cracking of the concrete at and below the surface. Thermal shock can be avoided by allowing the concrete to cool slowly so that the difference in the internal and external concrete temperature is minimal. For members that are less than 12 inches thick, the temperature of the surface of the concrete should not drop more than 50 degrees Fahrenheit in a 24 hour period. For 12 to 36 inch thick concrete this drop should not be more than 40 degrees Fahrenheit. For 36 to 72 inch-thick concrete the drop should not be more than 30 degrees Fahrenheit.

For vertically formed concrete, the drop in surface temperature may be controlled by loosening the forms but leaving them in place so that there is only a thin space between the concrete surface and the form

Figure 12–40 Chalky concrete surface

sheathing. This will retain some heat near the surface as the surface cools allowing the concrete to cool slowly. Regardless of the method used for controlling the rate of cooling, the rate of cooling should be monitored with a plan in place to slow the rate of cooling if necessary to comply with specification requirements or, if not specified, to slow the rate of cooling to comply with the guidelines mentioned.

Records of all concrete tests and weather conditions must be kept to aid in analyzing any deficiencies related to cold weather concrete placement. These should be specific to include time and location of temperature measurements and any observances that the inspector determines might be helpful in analyzing potential problems.

Further information on concrete placement in cold weather is available in ACI Standard 306, Recommended Practice for Cold Weather Concreting (ACI), and in PCA Engineering Bulletin 001, Design and Control of Concrete Mixtures (PCA).

The inspector's responsibilities related to cold weather concreting include verifying that:

- contractor's cold weather plan has been concurred in by the responsible engineer
- concrete is not ordered unless all systems and materials needed to implement the cold weather plan are on site
- concrete is protected from freezing for 24 hours, or longer if specified
- concrete is kept above 50 degrees Fahrenheit during the protection period
- flatwork that remains wet is protected from freezing until it attains 3,500 pounds per square inch compressive strength
- no more than 2 percent calcium chloride per 100 pounds of cement is added to the mix
- calcium chloride is strictly not allowed in steel reinforced concrete unless allowed by the specification
- aggregates and water are not heated above the specified maximum temperature

- except for sacrificial concrete, concrete is not placed on frozen subgrade or against forms that are 32 degrees Fahrenheit or colder
- concrete is not placed on subgrade that will settle an amount greater than that allowed by the design engineer
- concrete is at or above the minimum specified temperature when placed
- concrete temperature does not exceed the minimum temperature given in table 12–6 by more than 20 degrees Fahrenheit
- where applicable, wells are formed to allow pocket thermometers to be inserted into the concrete after the concrete hardens
- accuracy of thermometers used to monitor concrete and air temperature is verified
- when verifying concrete is at or above the minimum specified temperature, temperature measurements are taken where the concrete is suspected to be the coolest
- when monitoring temperature to access the potential for thermal shock, temperature measurements are taken where the concrete is suspected to be the warmest
- correct amount of installation is properly installed and maintained for the duration of the protection period or until other measures are in place to maintain the temperature within the specified range
- protection period is extended as necessary to gain the specified strength for concrete that is to be immediately put into service or otherwise loaded
- heated enclosures are vented to prevent carbonization of the concrete and protect employees from carbon dioxide poisoning
- attention is paid to curing, especially in heated enclosures
- concrete is allowed to cool slowly and at or below the specified cooling rate
- records of concreting in cold weather include all items that could help analyze deficiencies related to cold weather concrete

(t) Concreting in hot weather

In concrete work, hot weather is defined as the weather condition at the jobsite that causes acceleration in the rate of moisture loss or rate of cement hydration, including an ambient temperature of 80 degrees Fahrenheit or higher and an evaporation rate that exceeds 0.2 pounds per square foot of concrete surface per hour. The rate of moisture loss and rate of cement hydration may be accelerated if one or a combination of the following conditions exists:

- high ambient temperature
- high concrete temperature
- low relative humidity
- wind velocity
- solar radiation

Special measures are required for concrete placement in hot weather to control the concrete temperature and moisture loss. High concrete temperature and rapid moisture loss leads to rapid slump loss and the tendency for the contractor to add water to increase slump. The rapid slump loss reduces the amount of time the contractor has to place, consolidate, and finish the concrete. The addition of water increases the w/c which results in concrete that is weaker and less durable than a lower w/c mix. Entrained air will be lost quickly in hot concrete. Rapid moisture loss poses another problem for slab concrete. If the amount of moisture evaporating from the surface of a slab exceeds the amount of bleed water coming to the surface, the surface will dry out and crack; this is known as plastic shrinkage cracking.

The adverse effects of hot weather may be mitigated by some common sense measures such as:

- restrict placement to the most favorable time of the day such as early morning
- restrict the depth of layers in walls to limit cold joints
- increase workforce and equipment to allow quick placement of flatwork in an effort to limit edge cold joints
- increase the number of planned cold joints in flatwork to limit unplanned edge cold joints

- suspend placement until conditions improve
- restrict form removal, repair, and patching to small areas than can be finished and immediately covered with curing compound

Other measures to mitigate the adverse effects of hot weather are described herein.

A **hot weather concrete plan** is needed to address means and measures to control concrete temperature, maintain a workable slump during the placement period, attain the specified air content, and prevent plastic shrinkage cracking. The plan should address providing a relatively cool concrete mix that contains a set retarder to allow more time for mix transportation, placing, and finishing. The plan should address adding withheld water, air entrainment, and super-plasticizer at the site as applicable. It should also include measures for cooling forms and making sure forms and subgrade are moist at the time of placement. Monitoring bleed water, controlling the rate of bleed water evaporation, and prompt attention to curing should also be covered in the plan.

Concrete mix temperature is generally specified to be less than 90 degrees Fahrenheit; 95 degrees Fahrenheit if the concrete contains superplasticizer. Mix temperature can be controlled by using cool aggregates and cool water, by adding ice, by limiting mixing, limiting cement content, and by retarding the set. Substituting ice for batch water is more effective than using chilled batch water for cooling concrete because as ice melts it will consume heat from the mix. Shaved or crushed ice should be well incorporated into the mix and fully melt before the concrete is discharged from the mixer. Block ice should not be used because it may not fully melt before the mix is discharged. The amount of water and ice must never exceed the maximum amount of mixing water specified in the job mix. For every 1 pound of ice used, 1 pound of water will have to be deducted from the mix. Water weighs 8.3 pounds per gallon.

As concrete is mixed in a rotating drum, friction between the aggregates will create heat. In hot weather the mix should only be mixed the minimum amount necessary to provide a uniform mixture. This amount is generally 70 revolutions at mixing speed.

Mixtures containing higher contents of cement will be hotter because of the heat generated as the cement hydrates. Temperature can be lowered by retarding the set to reduce the amount of hydration that occurs before discharging the mix. Replacing some of the cement with a pozzolan such as fly ash will further serve to lower the heat of hydration.

Withholding some of the mix water and adding the amount withheld at the jobsite has shown to effectively increase the slump up to one inch over what it would be if all of the water were added at the batch plant. Slump can further be increased by adding a superplasticizer. It is best to add the superplasticizer at the jobsite as its effect is short lived, especially in hot weather. The effect of air entrainment is also short lived in hot weather making it necessary to add the air entraining additive at the jobsite if located a significant travel distance from the concrete batch plant.

For full and uniform distribution of admixtures, they must be added to the mix with some water; otherwise, they may only be incorporated into a portion of the mix. If this happens, the affected portion will be overdosed and the portion not receiving the admixture will not benefit from the admixture as intended. Therefore, if admixtures are to be added at the jobsite, some of the mix water must be withheld at the batch plant. This should be documented on the concrete delivery ticket so that the amount of withheld water can be quickly determined. Admixtures that have been added at the batch plant can be added again if necessary as long as enough water has been withheld, say about five gallons, so that they can be added with some water. Anything that is added to the mix must be fully incorporated and distributed throughout the mix by rotating the mixing drum 30 revolutions at mixing speed.

Record-tests for slump, temperature, and air content must be conducted at the beginning of the work and periodically to verify specification compliance. Even though record-tests must be taken from concrete sampled near the middle of the load, it is prudent in hot weather to test for temperature and air at the beginning of the load. Concrete cannot be rejected based on test results of concrete taken from the beginning of a load, but these tests results may prevent placing concrete that will have to be removed after the record-tests are made.

Temperature can quickly be measured with an accurate pocket thermometer (see pocket thermometer accuracy in the section on cold weather concrete). A quick air content test can be made with a Chace meter. See NEH645.1202, Sampling and Testing, for a description of the Chace meter. The Chace meter test is not approved for record/compliance testing; it is only an indicator of air content. If it shows there is only 1 to 2 percent air in the mix, the mix has not been air entrained or any air entrained into the mix has dissipated.

Hot forms can cause the concrete to stiffen quickly and limit the amount of time available for consolidating the concrete. This can lead to unplanned cold joints and honeycombing. When possible, forms should be shaded. They should be sprayed with cool water prior to being filled with concrete and be kept continuously wet for curing after being filled with concrete.

Subgrade and forms that are absorptive must be moist at the time of placement, so water is not absorbed from the mix; water which is needed to hydrate the cement must remain in the mix. Additionally, if the subgrade of a slab absorbs water from the mix, there will be limited or no bleedwater at the surface. This will likely result in plastic shrinkage cracking. Forms and subgrade must be moist, but not contain any standing water that could mix with concrete and increase the w/c.

Plastic shrinkage cracking has historically occurred in conventional concrete when the evaporation rate exceeds 0.2 pounds per square foot of concrete surface per hour. Figure 12–41 shows the effects of air temperature, relative humidity, concrete temperature, and wind velocity on the rate of evaporation. Lowering air temperature, concrete temperature, or wind speed, or increasing the relative humidity near the concrete will lower the evaporation rate. The evaporation rate for flat work and slab construction may be determined by calculating the evaporation rate from a shallow cake pan having a surface area of at least one square foot.

The chart in figure 12–41 can be used to predict the rate of evaporation if the air temperature, relative humidity, concrete temperature, and wind velocity are known. Begin by drawing a vertical line from the air temperature up to the point where the line intersects the relative humidity. From this point draw a horizontal to the right until it intersects the concrete temperature. From this point draw a vertical line down until it intersects the wind speed. Then draw a horizontal line from the this point to the left until it intersects the evaporation rate and read the evaporation rate where the line intersects the vertical axis labeled rate of evaporation, pound (ft^2/hr).

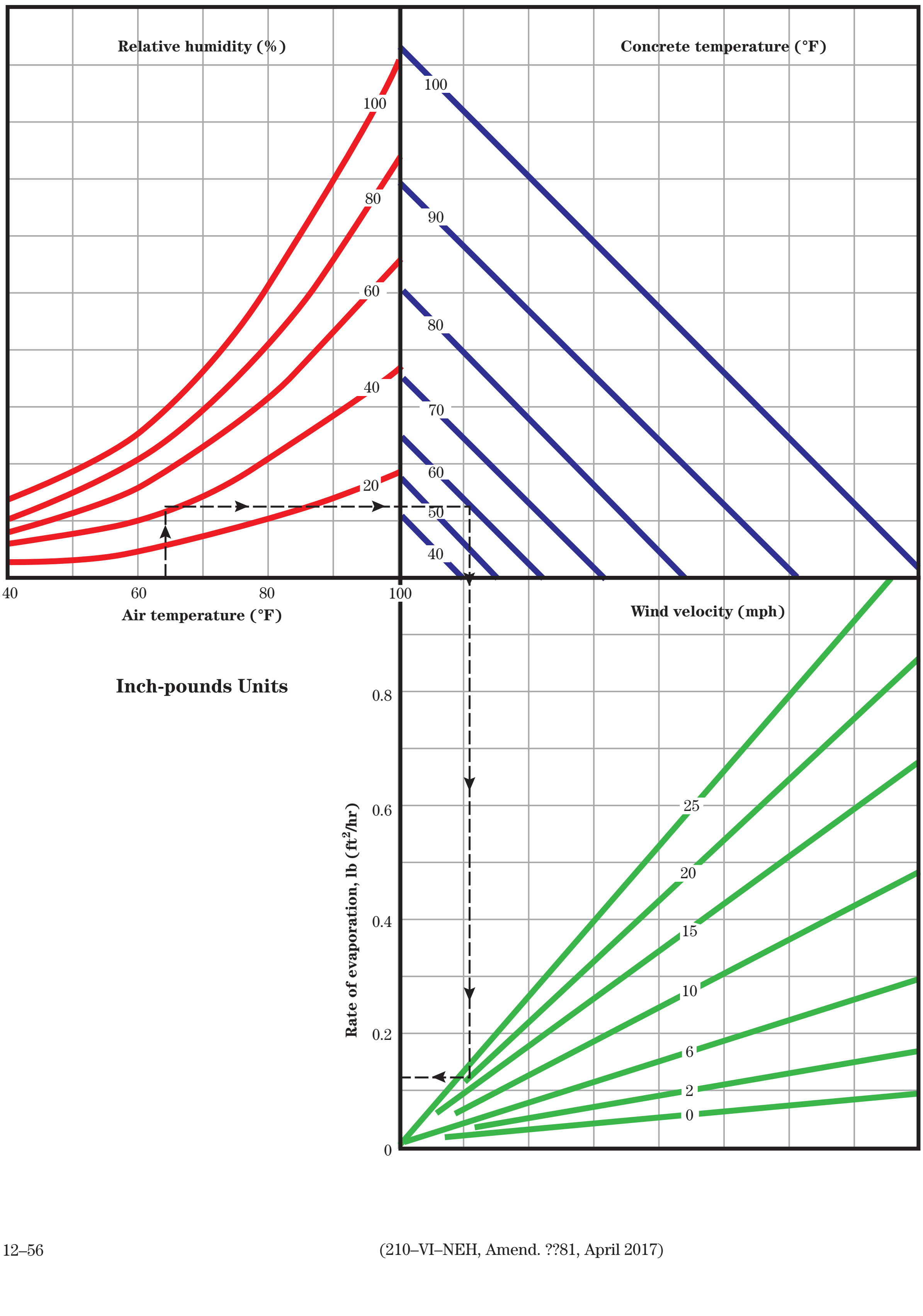
The air temperature and relative humidity near the concrete surface can be lowered and increased respectively by foggers or misters that emit a fine mist which evaporates before falling to the concrete surface. Sprayers that emit a larger water particle, one that falls on the concrete surface, should not be used as the surface may be damaged. Water should never be added to the concrete surface before the finishing operation and before the concrete sets up as this will increase the w/c at the surface.

Shielding the concrete from wind is a good practice when installing concrete flatwork in any weather. The height and position of the wind shield relative to the concrete will depend on the location, size, and orientation of the slab relative to the wind direction.

Concrete finishing operations can begin as soon as bleedwater ceases coming to the surface. If the rate of evaporation is high, it can be difficult to determine if bleedwater has ceased coming to the surface. It may be necessary to place a piece of wax coated paper or other opaque non-absorptive material on the concrete surface and periodically check to see if bleedwater has collected under it. The material should be shaded to limit the effect of solar heat on the material that could lead to a false reading. Wipe away any bleedwater and return the material to the surface until, when lifted, no bleedwater is observed between the concrete and the material. Then finishing operations can then begin.

Curing should commence as soon as the finishing operation is completed and the concrete has set up so that it is not damaged by the curing operation. Curing must not be delayed until after saw-cutting of slabs is completed. In hot weather, a white pigmented curing compound is beneficial by reflecting solar heat in addition to retaining moisture within the concrete. It is also a good indication of complete coverage of curing compound.

Figure 12–41 Evaporation chart (*courtesy of the PCA*)



Thermal shock can result if the water used for wet curing is substantially cooler than the concrete or if a change in weather rapidly cools the concrete. The concrete should cool no more than 5 degrees Fahrenheit per hour or 40 degrees Fahrenheit in a 24 hour period.

Records of all concrete tests and weather conditions should be kept to aid in analyzing any deficiencies related to hot weather concrete placement. These should be specific to include time and location of air temperature, wind, and humidity measurements and any observances that the inspector determines might be helpful in analyzing potential problems.

Further information on concrete placement in hot weather is available in ACI Standard 305, Recommended Practice for Hot Weather Concreting (ACI) and in PCA Engineering Bulletin 001, Design and Control of Concrete Mixtures (PCA).

The inspector's responsibilities related to hot weather concreting include verifying that:

- when specified, the contractor's hot weather plan has been concurred by the engineer
- when applicable, concrete placement is restricted to the most favorable time of day
- the depth of layers in walls is restricted to limit cold joints
- adequate workforce is available for quick placement of flatwork
- unplanned cold joints are kept to a minimum
- concrete is not placed if conditions preclude specification compliance
- form removal, repair, and patching is limited to small areas
- concrete mix temperature does not exceed the specified maximum
- all ice added to the mix has melted before the mix is discharged from the mixer
- block ice is not added to the mix
- amount of water and ice added to the mix does not exceed the total amount of mixing water allowed by the job mix
- mix revolutions are limit to within the specified range and preferably limited to the lower portion of the range
- when specified, the mix contains retarding additives
- when specified, the mix contains supplementary cementitious material
- admixtures are always added with some water
- amount of water and additives does not cause the mix water content to exceed that allowed by the job mix
- after admixtures are added, the concrete is mixed a minimum of 30 revolutions at mixing speed
- tests are conducted from concrete sampled near the beginning of the load as necessary to avoid installing noncompliant concrete
- record tests are only conducted from concrete sampled at two or more locations within the middle 60 percent of the load (ASTM C172/C172M)
- forms and subgrade are moistened before accepting concrete
- water is not standing on the subgrade or in forms at the time of concrete placement
- hot forms are cooled before accepting concrete
- foggers or misters are working properly during concrete placement
- large droplets are not sprayed on the surface of fresh concrete before setting
- wind shields are placed at the location and height to provide the best protection
- concrete finishing operations do not begin before bleedwater disappears
- finishing operations begin as soon as bleedwater disappears
- curing commences immediately after finishing operations
- curing water is not so cold that it will cause thermal shock
- records of concreting in hot weather include all tests, weather conditions, and any other items

that could help analyze deficiencies related to hot weather concrete

(u) Acceptance of concrete work

Items previously described pertain to compliance of all materials that are incorporated into the concrete, the job mix design, and the installation, finishing, and curing of the concrete. Two items remain that must be considered before accepting the concrete. These are: the concrete strength and the concrete dimensions and appearance.

Concrete strength is determined by a strength test. It is common for 28-day compressive strength to be specified. A 28-day compressive strength test is the average of the compressive strengths of two 28-day-old standard cured compressive strength specimens (cylinders) prepared and tested in accordance with an ASTM C39/C39M, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

It is common practice to test 7-day-old cylinders to estimate the concrete's 28 day strength. This may be done at the beginning of a job to learn the relationship between the job mix's 7- and 28-day strengths. As the job progresses, confidence in the relationship between the 7- and 28-day strengths may allow the contractor to make decisions based on the 7-day strength, such as deciding to continue placing concrete above previously placed concrete before the 28-day strength of the previously placed concrete is known. The relationship between the 7- and 28-day strengths varies widely from mix to mix, depending on the mix proportioning, amount and kind of cement in the mix, amount and kind of supplementary cementitious material in the mix, mix additives, curing effort, concrete and air temperature during and after placement, and other factors. Because this relationship varies from mix to mix and from season to season, it is best to error on the side of caution when making decisions based on 7-day strengths.

Documentation of the mix and placement location must accompany all strength test results. When concrete cylinders are made at the site, records must show where the concrete being tested was placed within the structure along with the results of index-tests (tests for air, slump, and concrete temperature) made.

Specifications generally allow some strength tests results to fall below the minimum specified strength because the minimum specified strength is generally set at a level above that needed for the structure to perform as designed. The ACI provides guidance on the acceptance of concrete based on strength. This often specified guidance states that the concrete strength is satisfactory if both the following requirements are met:

- no individual strength test falls more than 500 pounds per square inch below the specified compressive strength
- the average of any three consecutive strength tests is not less than the specified compressive strength

If the concrete fails to meet the specified criteria, the responsible engineer, in conjunction with the design engineer, should determine if the strength is adequate to carry the design loads. Durability cannot be quantified, but experience has shown that causes of low strength such as high w/c can also cause the concrete to be less durable. Both low strength and potential loss of durability should be considered when determining if the concrete may be accepted.

Sometimes cylinders that are mishandled or are improperly prepared and tested will yield errantly low strength results. If tests of compressive strength cylinders indicate that the concrete failed to meet the strength requirement, the contractor may choose to core the concrete and have the cores tested to confirm the results of tests on the cylinders. These cores should be obtained from the same concrete from which the cylinders that failed to meet strength requirements were made.

Cores generally test weaker than cylinders. Thus, specifications generally allow core strengths to be less than that of cylinder strengths. For instance, the specification may allow the average of three cores to be 85 percent of the specified strength as long any one core is not less than 75 percent of the specified strength.

There are some products on the market that can test in-place concrete strength in a "non-destructive" manner. One of these *non-destructive tests* is the rebound hammer. This is a spring loaded device that is held against the concrete surface in the recoiled position.

When it is triggered, the spring uncoils and causes a rod to impact the surface of the concrete. The rod rebounds an amount proportional to the hardness of the concrete surface. The device gives a numerical value associated with the rebound. This value can be compared through statistical analysis with known compressive strength values to estimate the in-place concrete strength. It requires a lot of testing with the hammer and results from some cores of the concrete to correlate the readings from the hammer to that of the cores.

Another device for estimating concrete strength fires a nail into the concrete. The depth of the nail is an indicator of concrete strength. As with the rebound hammer, the values from this device must be correlated to known compressive strength values and cores should be taken to verify the results.

Performing both non-destructive tests and taking cores has merit when the strength of a large quantity of concrete is in question; otherwise, only testing cores may be adequate.

Concrete dimensions are shown on the drawings and concrete appearance is generally specified in the construction specifications. Dimensional tolerances are specified along with requirements for finishing such as concrete rubbing with a carborundum stone, coatings, and surface textures. Common industry tolerances are given in appendix E.

The inspector's responsibilities related to acceptance of concrete work include verifying that:

- records of index tests and placement location are referenced to concrete cylinders
- cores are taken in same concrete that produced failed concrete cylinders
- concrete dimensions and finish comply with specification requirements

645.1202 Sampling and testing

This section covers tests performed by the NRCS inspector and others for quality control, quality assurance, and for as-built records and contract documentation. The actual procedures for sampling and testing are provided in ASTM test standards referenced in the specifications.

Materials that make up the job mix and other materials incorporated into the work are approved based on contractor submittals of material test results or certifications that materials comply with specification requirements. The responsible engineer should review all material submittals for specification compliance and provide the inspector a copy of the material submittal and approval document. Upon receipt of approval documentation, the inspector must list the material in the material certification section of the job diary as approved for use. Then, as materials are delivered to the site the inspector can verify that the materials are indeed those approved by the engineer.

The sampling and testing of fresh concrete is conducted by onsite quality control and quality assurance inspectors. Sampling for testing the hardened concrete is also done by quality control and quality assurance inspectors but the samples (cylinders) are generally sent to a qualified testing facility for testing. Cores are sampled and tested by a qualified testing facility.

(a) Materials in the job mix

(1) Admixtures

Chemical admixtures are tested and certified by the admixture manufacturer to meet the requirements of the ASTM admixture specification. There are no field tests for chemical admixtures.

(2) Aggregates

Aggregate quality must be determined prior to selecting aggregates for the job mix and during aggregate production to verify the aggregates continue to meet quality and gradation requirements.

ASTM standard test methods for determining if aggregates meet ASTM C33/C33M and NRCS Material Specification 522 requirements are bulleted below.

Most of the tests listed are not tests that an inspector in the field would be required to make. These tests are conducted in a laboratory for a material supplier to document specification compliance. The results of applicable tests should be submitted by the contractor to the responsible engineer as part of the mix design submittal.

If the concrete is batched and mixed at the jobsite, the inspector may be tasked with sampling and testing aggregates or sampling and sending them to a qualified testing laboratory.

- Tests for physical properties:
  - C88—Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
  - C127—Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
  - C128—Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate
  - C131—Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
  - C136—Test Method for Sieve Analysis of Fine and Coarse Aggregates
- Tests for deleterious substances:
  - C40—Test Method for Organic Impurities in Fine Aggregates for Concrete
  - C117—Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
  - C123—Test Method for Lightweight Particles in Aggregate (This test identifies coal, lignite, and chert)
  - C142—Test Method for Clay Lumps and Friable Particles in Aggregates
- Tests and guide for examination of aggregates for reactivity:
  - C227—Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
  - C289—Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)
  - C295—Standard Guide for Petrographic Examination of Aggregates for Concrete

Some of the tests listed may not be necessary. For example, tests for substances such as coal, lignite, chert, and reactive aggregate would not be needed if it is known that these do not exist at the aggregate source.

Some tests may only be needed if the results of other tests are positive. For example, if either C289 or C295 indicate an aggregate is reactive, C227 would be used to determine the effect of the aggregate reactivity on concrete made with the aggregate; otherwise, C227 would not be needed.

The best indications of how an aggregate will perform are the historical records of concrete made with the aggregate. These records include concrete strength test results and records of the concrete durability. The durability of concrete made from the aggregates and subjected to similar conditions as those expected for the project at hand is an indicator of how the concrete will perform. It is important to recognize that concrete may be durable in one environment and not durable when subjected to a different set of environmental conditions. Historical performance of aggregates and the concrete made with those aggregates is only relevant if the concrete for the project at hand will be subjected to the same environmental conditions.

Generally the aggregate supplier is responsible for providing test results to the concrete producer. The concrete producer may conduct mechanical sieve analysis to verify aggregates are graded according to specification requirements. Tests for aggregate moisture content should be conducted by the concrete supplier at the batch plant to determine the amount of free water the aggregates are contributing to the mix.

Tests for aggregate moisture—It is not common for the NRCS inspector to perform tests on individual concrete ingredients; however, the inspector may be asked to inspect the batch plant and check aggregate moistures if problems with concrete mix uniformity stem from poor aggregate moisture control is suspected. In arid climates, aggregates may be too dry. Dry aggregates absorb water and make it difficult to control the consistency of the mix. In humid climates, fine aggregates can contain fairly large amounts of free water that cause the mix to be too wet if add-water adjustments are not made.

Aggregate sampling is conducted in accordance with ASTM D75/D75M, Standard Practice for Sampling Aggregates. The main concern with sampling any material is being able to obtain a representative non-segregated sample. Samples from stockpiles must be obtained from various parts of the stockpiles, but never from the perimeter of the lower third of the pile. This is because the larger aggregates tend to segregate and roll to the perimeter of the pile. When sampling from a conveyor belt or stockpile, several samples should be taken and test results averaged to arrive at a value that is representative of a large portion of aggregate. Aggregates being sampled for moisture testing must immediately be placed into an airtight container and should be tested as soon as practicable after being collected.

ASTM standard test methods available for determining aggregate moisture are listed:

- C70, Test Method for Surface Moisture in Fine Aggregate
- D2216, Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- D4643, Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating
- D4944, Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester
- D4959, Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating

It is imperative to know if the test result represents the total moisture in the aggregate or just the moisture on the surface of the aggregate. For instance, if the moisture is determined according to ASTM D2216, the oven method, the test result will represent the total aggregate moisture (absorbed and surface moisture). The aggregate's absorption is subtracted from this value to determine the free water in the aggregate. If a Speedy (carbide) Moisture Meter (ASTM D4944) is used, the test value may only approximate the surface moisture, so the test result would likely be more representative of the free water in the aggregate. ASTM C70 is a test that yields only surface moisture on fine aggregate and its accuracy is dependent on knowing the relative density (specific gravity) of the aggregate. Results from shortcut methods such as the microwave method (ASTM D4643) or direct heating method (ASTM D4959), should be compared against the oven method. Since the oven method yields the true value of total aggregate moisture, results from all other total aggregate moisture test methods should be correlated with the oven method.

(3) Cementitious materials

The cementitious materials supplier provides the test results necessary to verify specification compliance for cementitious materials. If the quality or type of cement or supplementary cementitious material must be verified from a field sample, a representative sample should be sent to a laboratory that is qualified to make the necessary tests. If the NRCS inspector is tasked with obtaining a sample of cementitious material for quality assurance testing, contact the laboratory to determine the specified quantities and the sampling and shipping requirements needed to provide samples for testing.

(4) Water

Generally, water that is safe to drink is good for making concrete. It must be clean and free from injurious amounts of oil, salt, acid, alkali, organic matter, turbidity, or other deleterious substances.

NRCS concrete specifications do not require testing of the water used to make concrete, but ASTM C94 requires mixing water to comply with ASTM C1602/C1602M. ASTM C1602/C1602M requires water to meet a performance requirement. The performance requirement compares the strength and set time of concrete or mortar made with the water in question to that of concrete or mortar made with potable water or distilled water. ASTM C1602/C1602M also allows the purchaser to specify limits on one or more of four elements listed in the standard. If water testing is necessary, samples should be taken in a clean container that will not contaminate the water. Testing is typically done by an independent laboratory.

(b) The job mix

The following ASTM tests are conducted to verify and document specification compliance of fresh concrete.

- C138/C138M, Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- C143/C143M, Test Method for Slump of Hydraulic-Cement Concrete
- C173/C173M, Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
- C231/C231M, Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
- C1064/C1064M, Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete

To determine specification compliance, the concrete must be sampled in accordance with ASTM C172/C172M. For revolving drum mixers such as those used by ready-mix suppliers, ASTM C172/C172M requires the test sample to be obtained from two or more portions taken at regularly spaced intervals during discharge of the middle portion (the middle 20 to 80 percent) of the batch.

Specifications typically require the concrete be tested at the point of placement to verify the the slump, air content, and temperature are within the specified ranges. It is common for these tests to be conducted from concrete discharged near the beginning of the load so that the mix can be adjusted if necessary before it is placed. Any adjustments to the mix such as the addition of water and an additive require 30 revolutions of the mixing drum at mixing speed.

Test results from concrete that is first discharged from the mixer cannot be used to reject the mix. If tests made on concrete taken from the first part of the load indicate the concrete may not meet specification requirements for slump, air, or temperature, the contractor must decide if placing the concrete is worth the risk that tests from the middle of the load will prove otherwise.

Either of the two tests shown for air content may be used; however, the pressure method is not be suitable for concretes with porous aggregates. ASTM C138 is generally not used in the field for determining the air content of the mix since it is highly dependent on knowing the exact mix proportions and the relative density of each of the mix components. But information obtained from C138 is helpful when testing for mix uniformity. Variations in unit weight between batches that are not related to variations in measured air content indicate a problem with batching or mixing or both. Such uniformity variations must be corrected by the concrete supplier and uniformity tests conducted to document uniformity requirements.

The Chace air-meter is a device that can be used to estimate the air content of the mix (fig. 12–42). It only requires a small amount of paste and some isopropyl alcohol to return an air content value, but the test is not an approved ASTM standard test method and cannot be used to reject a mix. It can be used to determine if the concrete contains entrained air. If the Chace meter shows the concrete has less than two percent air, either the air entraining agent was not added to the mix or the entrained air has dissipated. When the Chace meter measures less than two percent air, ASTM C173/C173M or ASTM C231/C231M should be conducted to determine if the mix has the specified amount of entrained air.

Figure 12–42 Chace air-meter

If the mix is adjusted to correct either the slump, air content, or temperature (by adding ice), all of the tests should be conducted again. A common mistake is made when water or an additive is added to adjust the slump without testing the air content and temperature as both can be affected by the addition of water and additives and by the mixing necessary to incorporate them into the mix.

(c) Hardened concrete

Tests on hardened concrete include compressive strength tests and petrographic analysis. ASTM practice standards and test methods for sampling, testing, or examining hardened concrete are:

- C31/C31M - Standard Practice for Making and Curing Concrete Test Specimens in the Field
- C39/C39M - Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
- C42/C42M - Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- C856 - Standard Practice for Petrographic Examination of Hardened Concrete

Compressive strength test specimens are made according to ASTM C31/C31M or ASTM C42/C42M. The specimens are tested according to ASTM C39/C39M. NRCS inspectors are generally not tasked with testing specimens for strength, but must verify that specimens are obtained and cared for as specified in the applicable standards.

Specimens made according to ASTM C31/C31M (cylinders) should be made by a quality control inspector. Occasionally, NRCS inspectors will make cylinders, but it is generally best to leave that up to quality control or an assistant quality assurance inspector so that the NRCS inspector is not fully occupied making cylinders. A compressive strength test is the average strength of two standard cured cylinders tested 28 days after the cylinders are made. It is common practice to make at least one extra cylinder in case of improper sampling, molding, curing, or testing of the other cylinders. Sometimes extra cylinders are made and tested early (7 or 14 days) as an indicator of the 28-day strength (see the description on the relationship between 7 and 28 day strengths in section U, Acceptance of concrete work). Additional cylinders may be made and cured onsite near the structure if specifications state that forms can only to be removed after the concrete attains a minimum specified field strength.

When Construction Specification 94, Contractor Quality Control, is included in the specification package, the number and frequency of cylinders that must be made and tested is generally specified. It is sometimes specified that specimens must be made and tested to represent specific locations within the structure. The inspector should verify that the location, number, and sampling frequency of cylinders meets minimum requirements. The inspector should verify that the cylinders are made and treated according to ASTM C31/C31M and that the location in the structure where the concrete represented by the cylinders is placed is clearly documented. The inspector should verify that the slump, air content, and temperature of the concrete are tested and recorded as required by ASTM C31/C31M whenever cylinders are made.

Construction Specification 31 allows one out of every three consecutive compressive tests to fall below the specified strength by up to 500 pounds per square inch. The inspector should maintain a chronological list of 28-day strength test results in order to verify specified strength requirements are met. The list should also include the results of slump, air content, and temperature of the concrete from which the cylinders were made.

It may be necessary to test the compressive strength of in-place concrete. If strength test results from concrete cylinders indicate concrete strengths below the specified minimum strength, the contractor is generally allowed to prove the in place concrete meets the strength requirements. This is accomplished by coring and testing the concrete and reporting the test results according to ASTM C42/C42M. It is important to note that compressive strength test results of cores are affected by the length to diameter ratio of cores and also by the diameter of the cores. Larger diameter cores and those with a higher length to diameter ratio tend to test higher than those with smaller diameters and small length to diameter ratios near 1.

There are some non-destructive tests for indicating the strength of hardened concrete; however, their accuracy should be verified by testing concrete cores according to ASTM C42/C42M.

When cores are taken, the inspector should verify that they are taken from the portion of concrete in question and that efforts to avoid cutting through steel reinforcement are made.

Petrographic analysis is conducted on hardened concrete in accordance with ASTM C856. The analysis requires cutting a slice from a concrete specimen and polishing the surface of the sliced sample for close visual examination. The polished sample is examined by a qualified petrographer under microscope or an image of the sample is taken and expanded for a microscopic view. Petrographic analysis is generally not required to verify specification compliance; however, it may be required if there are questions to be answered about the hardened concrete. Several things can be learned from a petrographic analysis some of which are: the makeup of the concrete, the amount of entrapped and entrained air, the spacing and orientation of air voids, and the presence of reactive aggregate. The inspector may be asked to inspect the sampling of hardened concrete that will be examined petrographically and document the location where samples are taken.

(d) Other materials incorporated into the concrete work

These materials are tested by the material manufacturer.

- concrete coatings
- curing compound
- dowels
- metal plates
- preformed expansion joint filler
- sealing compound for joints
- steel reinforcement
- waterstops

The supplier should provide proof or certification (depending on contract requirements) that the materials comply with specification requirements. Testing of these materials in the field is not required, but it is incumbent on the inspector to verify and document that the installed materials have been approved, by the responsible engineer, to be incorporated into the work.

645.1203 Records and reports

These records and reports are related to concrete:

- Daily Diary—used to record the day-to-day activities of construction including concrete activities
- 645 WS 12.1 Certification of Materials and Concrete Mixture—for recording concrete job mix materials and proportioning
- 645 WS 12.2 Concrete Trial Mix—used for trial mixes when proportioning a concrete mix
- 645 WS 12.3 Report on Concrete Test Specimens —for making a chronological record of concrete strength results”

These records and reports provide for systematic recording of information needed for documenting specification compliance. Some of the worksheets may not be needed if the contractor or concrete supplier provides the information on their own worksheets or forms. For more detail on the use of the worksheets see appendix B. Appendix B contains blank worksheets, guidance on filling out the worksheets, and example worksheets.

Appendix C contains an example of a typical diary entry related to concrete construction.

645.1204 References

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