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CIP 100 - CONCRETE IN PRACTICE

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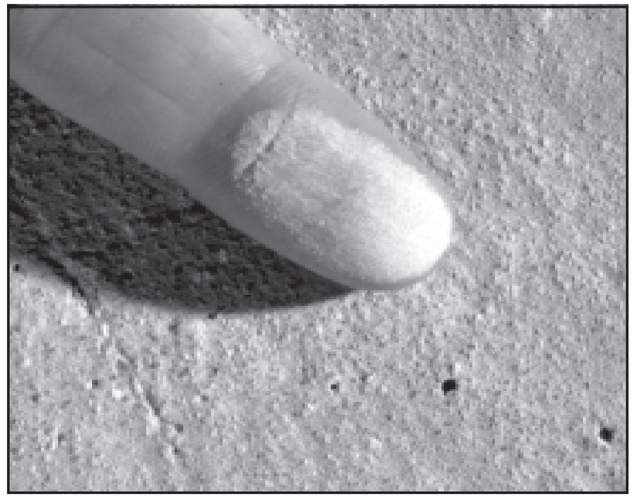
CIP 1 - Dusting Concrete Surfaces

WHAT is Dusting

Formation of loose powder resulting from disintegration of surface of hardened concrete is called dusting or chalking. The characteristics of such surfaces are:

a. They powder under any kind of traffic

b. They can be easily scratched with a nail or even by sweeping.



Dusting concrete surface

WHY Do Concrete Floors Dust

A concrete floor dusts under traffic because the wearing surface is weak. This weakness can be caused by:

a. Any finishing operation performed while bleed water is on the surface or before the concrete has finished bleeding. Working this bleed water back into the top 1/4 inch [6 mm] of the slab produces a very high water-cement ratio and, therefore, a low strength surface layer.

b. Placement over a non-absorptive subgrade or polyethylene vapor retarder. This reduces normal absorption by the subgrade, increases bleeding and, as a result, the risk of surface dusting.

c. Floating and/or troweling operations following the condensation of moisture from warm humid air on cold concrete. In cold weather concrete sets slowly, in particular, cold concrete in basement floors. If the humidity is relatively high, water will condense on the freshly placed concrete, which, if troweled into the surface, will cause dusting.

d. Inadequate ventilation in enclosed spaces. Carbon dioxide from open salamanders, gasoline engines or generators, power buggies or mixer engines may cause a chemical reaction known as carbonation, which greatly reduces the strength and hardness of the concrete surface.

e. Insufficient curing. This omission often results in a soft surface skin, which will easily dust under foot traffic.

f. Inadequate protection of freshly placed concrete from rain, snow or drying winds. Allowing the concrete surface to freeze will weaken the surface and result in dusting.

HOW to Prevent Dusting

a. Concrete with the lowest water content with an adequate slump for placing and finishing will result in a strong, durable, and wear-resistant surface. In general, use concrete with a moderate slump not exceeding 5 inches [125 mm]. Concrete with a higher slump may be used provided the mixture is designed to produce the required strength without excessive bleeding and/or segregation. Water-reducing admixtures are typically used to increase slump while maintaining a low water content in the mixture. This is particularly important in cold weather when delayed set results in prolonged bleeding.

b. *NEVER* sprinkle or trowel dry cement into the surface of plastic concrete to absorb bleed water. Remove bleed water by dragging a garden hose across the surface. Excessive bleeding of concrete can be reduced by using air-entrained concrete, by modifying mix proportions, or by accelerating the setting time.

c. *DO NOT* perform any finishing operations with water present on the surface or while the concrete continues to bleed. Initial screeding must be promptly followed by bull floating. Delaying bull floating operations can cause bleed water to be worked into surface layer. Do not use a jitterbug, as it tends to bring excess mortar to the surface. *DO NOT* add water to the surface to facilitate finishing operations.

d. Do not place concrete directly on polyethylene vapor retarders or non-absorptive subgrades as this can contribute to problems such as dusting, scaling, and cracking. Place 3 to 4 inches [75 to 100 mm] of a trimable, compactible fill, such as a crusher-run material, over vapor retarders or non-absorptive subgrade prior to concrete placement. When high evaporation rates exist, lightly dampen absorptive subgrades just prior to concrete placement, ensuring that water does not pond or collect on the subgrade surface.

e. Provide proper curing by using liquid membrane curing compound or by covering the surface with water, wet burlap, or other curing materials as soon as possible after finishing to retain moisture in the slab. It is important to protect concrete from the environment at early ages.

f. Placing concrete in cold weather requires concretetemperatures exceeding 50°F [10°C] as well as an accelerating admixture.

HOW to Repair Dusting

a. Sandblast, shot blast or use a high-pressure washer to remove the weak surface layer.

b. To minimize or eliminate dusting, apply a commercially available chemical floor hardener, such as sodium silicate (water glass) or metallic zinc or magnesium fluosilicate, in compliance with manufacturer's directions on thoroughly dried concrete. If dusting persists, use a coating, such as latex formulations, epoxy sealers, or cement paint.

c. In severe cases, a serviceable floor can be obtained by wet-grinding the surface to durable substrate concrete. This may be followed by properly bonded placement of a topping course. If this is not practical, installation of a floor covering, such as carpeting or vinyl tile covering, is the least expensive solution to severe dusting. This option will require some prior preparation since adhesives for floor covering materials will not bond to floors with a dusting problem and dusting can permeate through carpeting.

References

1. *Guide for Concrete Floor and Slab Construction*, ACI 302.1R. American Concrete Institute, Farmington Hills, MI.
2. *Slabs on Grade*, Concrete Craftsman Series CCS-1, American Concrete Institute, Farmington Hills, MI.
3. *Concrete Slab Surface Defects: Causes, Prevention, Repair*, IS177, Portland Cement Association, Skokie, IL
4. *The Effect of Various Surface Treatments, Using Zinc and Magnesium Fluosilicate Crystals on Abrasion Resistance of Concrete Surfaces*, Concrete Laboratory Report No. C-819, U.S. Bureau of Reclamation.
5. *Residential Concrete*, National Association of Home Builders, Washington, DC.
6. *Trouble Shooting Guide for Concrete Dusting*, Concrete Construction, April 1996.

Follow These Rules to Prevent Dusting

1. Use moderate slump concrete not exceeding 5 inches [125 mm].
2. Do not start finishing operation while the concrete is bleeding.
3. Do not broadcast cement or sprinkle water on concrete prior to or during finishing operations.
4. Ensure that there is adequate venting of exhaust gases from gas-fired heaters in enclosed spaces.
5. Use adequate curing measures to retain moisture in concrete for the first 3 to 7 days and protect it from

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CIP 2 - Scaling Concrete Surfaces

WHAT is Scaling

Scaling is local flaking or peeling of a finished surface of hardened concrete as a result of exposure to freezing and thawing. Generally, it starts as localized small patches which later may merge and extend to expose large areas. Light scaling does not expose the coarse aggregate. Moderate scaling exposes the aggregate and may involve loss of up to 1/8 to 3/8 inch [3 to 10 mm] of the surface mortar. In severe scaling more surface has been lost and the aggregate is clearly exposed and stands out.

Note—Occasionally concrete peels or scales in the absence of freezing and thawing. This type of scaling is not covered in this CIP. Often this is due to the early use of a steel trowel, over-finishing or finishing while bleed water is on the surface. (see CIP 20 on Delaminations)

Scaling concrete surface

WHY Do Concrete Surfaces Scale

Concrete slabs exposed to freezing and thawing in the presence of moisture and/or deicing salts are susceptible to scaling. Most scaling is caused by:

a. The use of *non-air-entrained concrete* or too little entrained air. Adequate air entrainment is required for protection against freezing and thawing damage. However, even air-entrained concrete will scale if other precautions, as listed below, are not observed.

b. Application of excessive amounts of calcium or sodium chloride deicing salts on concrete with inadequate strength, air entrainment, or curing. Chemicals such as ammonium sulfate or ammonium nitrate, which are components of most fertilizers, can cause scaling as well as induce severe chemical attack on the concrete surface.

c. Any finishing operation performed while bleed water is on the surface. If bleed water is worked back into the top surface of the slab, a high water-cement ratio and, therefore, a low-strength surface layer is produced. Overworking the surface during finishing will reduce the air content in the surface layer, making it susceptible to scaling in freezing conditions.

d. Insufficient curing. This omission often results in a weak surface skin, which will scale if it is exposed to freezing and thawing in the presence of moisture and deicing salts.

HOW to Prevent Scaling

a. Concrete exposed to freezing and thawing cycles must be air-entrained. Severe exposures require air contents of 6 to 7 percent in freshly mixed concrete made with 3/4-inch [19 mm] or 1-inch [25-mm] aggregate. In moderate exposures, where deicing salts will not be used, 4 to 6 percent air will be sufficient. Air-entrained concrete of moderate slump (up to 5 inches [125 mm]) and adequate quality should be used. In general, concrete strength of 3500 psi [24 MPa] for freezing and thawing exposure and 4000 psi [28 MPa] when deicers are used should be adequate to prevent scaling.

b. *DO NOT* use deicing salts, such as calcium or sodium chloride, in the first year after placing the concrete. Use clean sand for traction. When conditions permit, hose off accumulation of salt deposited by cars on newly placed driveways and garage slabs. Subsequently, use salt sparingly. *Never use ammonium sulfate or ammonium nitrate as a deicer;* these are chemically aggressive and destroy concrete surfaces. Poor drainage, which permits water or salt and water to stand on the surface for extended periods of time, greatly increases the severity of the exposure and may cause scaling. (This is often noticed in gutters and sidewalks where the snow from plowing keeps the surface wet for long periods of time.)

c. Provide proper curing by using liquid membrane curing compound or by covering the surface of newly placed slab with wet burlap. Curing ensures the proper reaction of cement with water, known as hydration, which allows the concrete to achieve its highest potential strength.

d. *DO NOT* perform any finishing operations with water present on the surface. Bull floating must promptly follow initial screeding. Delay finishing operations until all the bleed water has risen to and disappeared from the surface. This is critical with air-entrained concrete in dry and windy conditions where concrete that is continuing to bleed may appear dry on the surface.

e. Do not use a jitterbug or vibrating screed with high slump concrete, as it tends to form a weak layer of mortar on the surface.

f. Protect concrete from the harsh winter environment. It is important to prevent the newly placed concrete from becoming saturated with water prior to freeze and thaw cycles during winter months. Apply a commercially available silane or siloxane-based breathable concrete sealer or water repellent specifically designed for use on concrete slabs. Follow the manufacturer's recommendations for application procedures and frequency. Another option is a 1:1 mixture of boiled linseed oil and mineral spirits applied in two layers. The concrete should be reasonably dry prior to the application of a sealer. Late summer is the ideal time for surface treatment. The sealer can be sprayed, brushed, or rolled on the surface of the concrete. *CAUTION:* Linseed oil will darken the color of the concrete and care should be taken to apply it uniformly.

HOW to Prevent Scaled Surfaces

The repaired surface will only be as strong as the base surface to which it is bonded. Therefore, the surface to be repaired should be free of dirt, oil or paint and, most importantly, it must be sound. To accomplish this, use a hammer and chisel, sandblasting, high-pressure washer, or jack hammer to remove all weak or unsound material. The clean, rough, textured surface is then ready for a thin bonded resurfacing such as:

a. Portland cement concrete resurfacing
b. Latex modified concrete resurfacing
c. Polymer-modified cementitious-based repair mortar

References

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2. *Scale-Resistant Concrete Pavements,* IS117.02P, Portland Cement Association, Skokie, IL.
3. *Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals*, National Cooperative Highway Research Program Report No. 16.
4. *Guide for Concrete Floor and Slab Construction*, ACI 302.1R, American Concrete Institute, Farmington Hills, MI.
5. *Residential Concrete*, National Association of Home Builders, Washington, DC.
6. *Slabs on Grade*, Concrete Craftsman Series CCS-1, American Concrete Institute, Farmington Hills, MI.
7. Eugene Goeb, *Deicer Scaling: An Unnecessary Problem*, Concrete Products, February 1994.

Follow These Rules to Prevent Scaling

1. For moderate to severe exposures, use air-entrained concrete of medium slump (3-5 in. [75-125 mm]) and cure properly.
2. Do not use deicers in the first winter.
3. Seal the surface with a commercial sealer or a mixture of boiled linseed oil and mineral spirits.
4. Use correct timing for all finishing operations and avoid the use of steel trowels for exterior concrete slabs.
5. Specify air-entrained concrete. In cold weather, concrete temperature should be at least 50°F [10°C], contain an accelerating admixture, and be placed at a lower slump.

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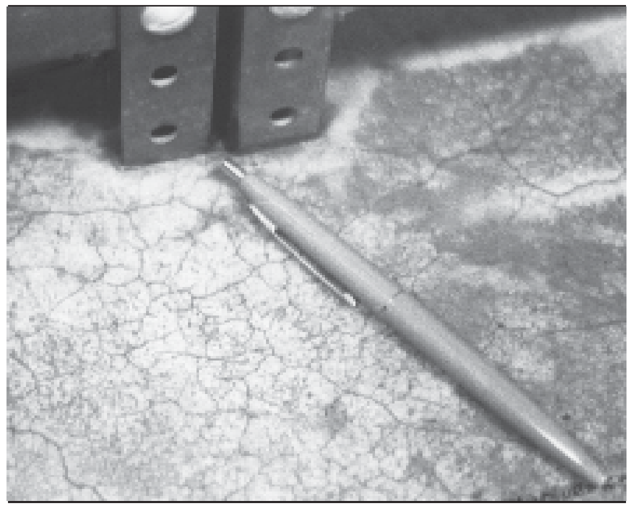
CIP 3 - Crazing Concrete Surfaces

WHAT is Crazing?

Crazing is the development of a network of fine random cracks or fissures on the surface of concrete or mortar caused by shrinkage of the surface layer. These cracks are rarely more than $^{1}/_{8}$ inch [3 mm] deep and are more noticeable on steel-troweled surfaces. The irregular hexagonal areas enclosed by the cracks are typically no more than $1^{1}/_{2}$ inch [40 mm] across and may be as small as $^{1}/_{2}$ or $^{3}/_{8}$ inch [12 or 20 mm] in unusual instances. Generally, craze cracks develop at an early age and are apparent the day after placement or at least by the end of the first week. Often they are not readily visible until the surface has been wetted and it is beginning to dry out.

Crazing cracks are sometimes referred to as shallow map or pattern cracking. They do not affect the structural integrity of concrete and rarely do they affect durability or wear resistance. However, crazed surfaces can be unsightly. They are particularly conspicuous and unsightly when concrete contains calcium chloride, a commonly used accelerating admixture.



Crazing Concrete Surface (Dampened)

WHY Do Concrete Surfaces Craze?

Concrete surface crazing usually occurs because one or more of the rules of "good concrete practices" were not followed. The most frequent violations are:

a. Poor or inadequate curing. Environmental conditions conducive to high evaporation rates, such as low humidity, high temperature, direct sunlight, and drying winds on a concrete surface when the concrete is just beginning to gain strength, cause rapid surface drying resulting in craze cracking. Avoid the delayed application of curing or even intermittent wet curing and drying after the concrete has been finished.

b. Too wet a mix, excessive floating, the use of a jitterbug or any other procedures that will depress the coarse aggregate and produce an excessive concentration of cement paste and fines at the surface.

c. Finishing while there is bleed water on the surface or the use of a steel trowel at a time when the smooth surface of the trowel brings up too much water and cement fines. Use of a bull float or darby with water on the surface or while the concrete continues to bleed will produce a high water-cement ratio, weak surface layer which will be susceptible to crazing, dusting and other surface defects.

d. Sprinkling cement on the surface to dry up the bleed water is a frequent cause of crazing. This concentrates fines on the surface. Spraying water on the concrete surface during finishing operations will result in a weak surface susceptible to crazing or dusting.

e. Occasionally carbonation of the surface results in crazing as it causes shrinkage of the surface layer. Carbonation is a chemical reaction between cement and carbon dioxide or carbon monoxide from unvented heaters. In such instances the surface will be soft and will dust as well.

HOW to Prevent Crazing?

a. To prevent crazing, start curing the concrete as soon as possible. Keep the surface wet by either flooding with water, covering it with damp burlap and keeping it continuously moist for a minimum of 3 days, or spraying the surface with a liquid-membrane curing compound. Avoid alternate wetting and drying of concrete surfaces at an early age. Curing retains the moisture required for proper reaction of cement with water, called hydration.

b. Use moderate slump (3 to 5 inches [75 to 125 mm]) concrete. Higher slump (up to 6 or 7 inches [150 to 175 mm]) can be used provided the mixture is designed to produce the required strength without excessive bleeding and/or segregation. This is generally accomplished by using water-reducing admixtures.

c. *NEVER* sprinkle or trowel dry cement or a mixture of cement and fine sand on the surface of the plastic concrete to absorb bleed water. *DO NOT* sprinkle water on the slab to facilitate finishing. Remove bleed water by dragging a garden hose across the surface. *DO NOT* perform any finishing operation while bleed water is present on the surface or before the bleeding process is completed. *DO NOT* overwork or over-finish the surface.

d. When high evaporation rates are possible, lightly dampen the subgrade prior to concrete placement to prevent it absorbing too much water from the concrete. If a vapor retarder is required on the subgrade, cover it with 3 to 4 inches of a compactible, granular fill, such as a crusher-run material to reduce bleeding.

References

1. *Guide for Concrete Floor and Slab Construction*, ACI 302.1R, American Concrete Institute, Farmington Hills, MI.

2. *Concrete Slab Surface Defects: Causes, Prevention, Repair*, IS 177T, Portland Cement Association, Skokie, IL.

3. Ward Malisch, *Avoiding Common Outdoor Flatwork Problems,* Concrete Construction, July 1990.

4. Ralph Spannenberg, *Use the Right Tool at the Right Time,* Concrete Construction, May 1996.

Follow These Rules to Prevent Crazing

1. Use moderate slump (3-5 inches) concrete with reduced bleeding characteristics.
2. Follow recommended practices and timing, based on concrete setting characteristics, for placing and finishing operations:
   a. Avoid excessive manipulation of the surface, which can depress the coarse aggregate, increase the cement paste at the surface, or increase the water-cement ratio at the surface.
   b. *DO NOT* finish concrete before the concrete has completed bleeding. *DO NOT* dust any cement onto the surface to absorb bleed water. *DO NOT* sprinkle water on the surface while finishing concrete.
   c. When steel troweling is required, delay it until the water sheen has disappeared from the surface.
3. Cure properly as soon as finishing has been completed.

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CIP 4 - Cracking Concrete Surfaces

WHAT are Some Forms of Cracks?

Concrete, like other construction materials, contracts and expands with changes in moisture and temperature, and deflects depending on load and support conditions. Cracks can occur when provisions to accommodate these movements are not made in design and construction. Some forms of common cracks are:

Figure A: Plastic shrinkage cracks (See CIP 5)

Figure B: Cracks due to improper jointing (See CIP 6)

Figure C: Cracks due to continuous external restraint (Example: Cast-in-place wall restrained along bottom edge of footing)

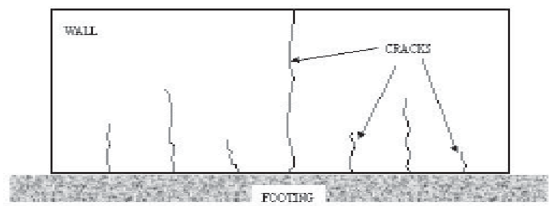
Figure D: Cracks due to lack of an isolation joint (See CIP 6)

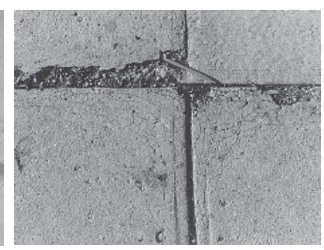
Figure E: D-Cracks from freezing and thawing

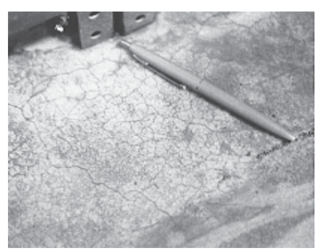
Figure F: Craze Cracks (See CIP 3)

Figure G: Settlement cracks

Most random cracks that appear at an early age, although unsightly, rarely affect the structural integrity or the service life of concrete. Closely spaced pattern cracks or D-cracks due to freezing and thawing, that typically appear at later ages, are an exception and may lead to ultimate deterioration.







WHY Do Concrete Surfaces Crack?

The majority of concrete cracks usually occur due to improper design and construction practices, such as:

a. Omission of isolation and contraction joints and improper jointing practices.
b. Improper subgrade preparation.
c. The use of high slump concrete or excessive addition of water on the job.
d. Improper finishing.
e. Inadequate or no curing.

HOW to Prevent or Minimize Cracking?

All concrete has a tendency to crack and it is not posbasic concreting practices are observed:

a. *Subgrade and Formwork*. All topsoil and soft spots should be removed. The soil beneath the slab should be compacted soil or granular fill, well compacted by rolling, vibrating or tamping. The slab, and therefore, the subgrade, should be sloped for proper drainage. In winter, remove snow and ice prior to placing concrete and do not place concrete on a frozen subgrade. Smooth, level subgrades help prevent cracking. All formwork must be constructed and braced so that it can withstand the pressure of the concrete without movement. Vapor retarders directly under a concrete slab increase bleeding and greatly increase the potential for cracking, especially with high-slump concrete. When a vapor retarder is used, cover it with 3 to 4 inches of a compactible granular fill, such as a crusher-run material to reduce bleeding. Immediately prior to concrete placement, lightly dampen the subgrade, formwork, and the reinforcement if severe drying conditions exist.

b. *Concrete*. In general, use concrete with a moderate slump (not over 5 inches [125 mm]). Avoid retempering concrete to increase slump prior to placement. Higher slump (up to 6 or 7 inches [150 to 175 mm]) can be used provided the mixture is designed to produce the required strength without excessive bleeding and/or segregation. This is generally accomplished by using water-reducing admixtures. Specify air-entrained concrete for outdoor slabs subjected to freezing weather. (See CIP 2)

c. *Finishing*. Initial screeding must be promptly followed by bull floating. DO NOT perform finishing operations with water present on the surface or before the concrete has completed bleeding. Do not overwork or over-finish the surface. For better traction on exterior surfaces use a broom finish. When ambient conditions are conducive to a high evaporation rate, use means to avoid rapid drying and associated plastic shrinkage cracking by using wind breaks, fog sprays, and covering the concrete with wet burlap or polyethylene sheets between finishing operations.

d. *Curing*. Curing is an important step to ensure durable crack-resistant concrete. Start curing as soon as possible. Spray the surface with liquid membrane curing compound or cover it with damp burlap and keep it moist for at least 3 days. A second application of curing compound the next day is a good quality assurance step.

e. *Joints*. Anticipated volumetric changes due to temperature and/or moisture should be accommodated by the construction of contraction joints by sawing, forming or tooling a groove about $^1/_4$ to $^1/_3$ the thickness of the slab, with a spacing between 24 to 36 times the thickness. Tooled and saw-cut joints should be run at the proper time (CIP 6). A maximum 15 feet spacing for contraction joints is often recommended. Panels between joints should be square and the length should not exceed about 1.5 times the width. Isolation joints should be provided whenever restriction to freedom of either vertical or horizontal movement is anticipated—such as where floors meet walls, columns, or footings. These are full-depth joints and are constructed by inserting a barrier of some type to prevent bond between the slab and the other elements.

f. *Cover Over Reinforcement*. Providing sufficient concrete cover (at least 2 inches [50 mm]) to keep salt and moisture from contacting the steel should prevent cracks in reinforced concrete caused by expansion of rust on reinforcing steel.

References

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2. *Guide for Concrete Floor and Slab Construction,* ACI 302.1R, American Concrete Institute, Farmington Hills, MI.
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4. Grant T. Halvorson, *Troubleshooting Concrete Cracking During Construction,* Concrete Construction, October 1993.
5. *Cracks in Concrete: Causes, Prevention, Repair*, A collection of articles from Concrete Construction Magazine, June 1973.

Follow These Rules to Minimize Cracking

1. Design the members to handle all anticipated loads.
2. Provide proper contraction and isolation joints.
3. In slab on grade work, prepare a stable subgrade.
4. Place and finish according to recommended and established practices.
5. Protect and cure the concrete properly.

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CIP 5 - Plastic Shrinkage Cracking

WHAT is Plastic Shrinkage Cracking?

Plastic shrinkage cracks appear in the surface of fresh concrete soon after it is placed and while it is still plastic. These cracks appear mostly on horizontal surfaces. They are usually parallel to each other on the order of 1 to 3 feet apart, relatively shallow, and generally do not intersect the perimeter of the slab. Plastic shrinkage cracking is highly likely to occur when high evaporation rates cause the concrete surface to dry out before it has set.

Plastic shrinkage cracks are unsightly but rarely impair the strength or durability of concrete floors and pavements. The development of these cracks can be minimized if appropriate measures are taken prior to and during placing and finishing concrete.

(Note: Plastic shrinkage cracks should be distinguished from other early or prehardening cracks caused by settlement of the concrete around reinforcing bars, formwork movement, early age thermal cracking, or differential settlement at a change from a thin to a deep section of concrete.)

WHY Do Plastic Shrinkage Cracks Occur?

Plastic shrinkage cracks are caused by a rapid loss of water from the surface of concrete before it has set. The critical condition exists when the rate of evaporation of surface moisture exceeds the rate at which rising bleed water can replace it. Water receding below the concrete surface forms menisci between the fine particles of cement and aggregate causing a tensile force to develop in the surface layers. If the concrete surface has started to set and has developed sufficient tensile strength to resist the tensile forces, cracks do not form. If the surface dries very rapidly, the concrete may still be plastic, and cracks do not develop at that time; but plastic cracks will surely form as soon as the concrete stiffens a little more. Synthetic fiber reinforcement incorporated in the concrete mixture can help resist the tension when concrete is very weak.

Plastic Shrinkage Cracks

Conditions that cause high evaporation rates from the concrete surface, and thereby increase the possibility of plastic shrinkage cracking, include:

- Wind velocity in excess of 5 mph
- Low relative humidity
- High ambient and/or concrete temperatures

Small changes in any one of these factors can significantly change the rate of evaporation. ACI 305 (ref. 1) provides a chart to estimate the rate of evaporation and indicates when special precautions might be required. However, the chart isn't infallible because many factors other than rate of evaporation are involved.

Concrete mixtures with an inherent reduced rate of bleeding or quantity of bleed water are susceptible to plastic shrinkage cracking even when evaporation rates are low. Factors that reduce the rate or quantity of bleeding include high cementitious materials content, high fines content, reduced water content, entrained air, high concrete temperature, and thinner sections. Concrete containing silica fume requires particular attention to avoid surface drying during placement.

Any factor that delays setting increases the possibility of plastic shrinkage cracking. Delayed setting can result from a combination of one or more of the following: cool weather, cool subgrades, high water contents, lower cement contents, retarders, some water reducers, and supplementary cementing materials.

HOW to Minimize Plastic Shrinkage Cracking?

Attempts to eliminate plastic shrinkage cracking by modifying the composition to affect bleeding characteristics of a concrete mixture have not been found to be consistently effective. To reduce the potential for plastic shrinkage cracking, it is important to recognize ahead of time, before placement, when weather conditions conducive to plastic shrinkage cracking will exist. Precautions can then be taken to minimize its occurrence.

a. When adverse conditions exist, erect temporary windbreaks to reduce the wind velocity over the surface of the concrete and, if possible, provide sunshades to control the surface temperature of the slab. If conditions are critical, schedule placement to begin in the later afternoon or early evening. However, in very hot conditions, early morning placement can afford better control on concrete temperatures.

b. In the very hot and dry periods, use fog sprays to discharge a fine mist upwind and into the air above the concrete. Fog sprays reduce the rate of evaporation from the concrete surface and should be continued until suitable curing materials can be applied.

c. If concrete is to be placed on a dry absorptive subgrade in hot and dry weather, dampen the subgrade but not to a point that there is freestanding water prior to placement. The formwork and reinforcement should also be dampened.

d. The use of vapor retarders under a slab on grade greatly increases the risk of plastic shrinkage cracking. If a vapor retarder is required, cover it with a 3 to 4 inch lightly dampened layer of a trimable, compactible granular fill, such as a crusher-run material (ref. 2).

e. Have proper manpower, equipment, and supplies on hand so that the concrete can be placed and finished promptly. If delays occur, cover the concrete with moisture-retaining coverings, such as wet burlap, polyethylene sheeting or building paper, between finishing operations. Some contractors find that plastic shrinkage cracks can be prevented in hot dry climates by spraying an evaporation retardant on the surface behind the screeding operation and following floating or troweling, as needed, until curing is started.

f. Start curing the concrete as soon as possible. Spray the surface with liquid membrane curing compound or cover the surface with wet burlap and keep it continuously moist for a minimum of 3 days.

g. Consider using synthetic fibers (ASTM C 1116) to resist plastic shrinkage cracking.

h. Accelerate the setting time of concrete and avoid large temperature differences between concrete and air temperatures.

If plastic shrinkage cracks should appear during final finishing, the finisher may be able to close them by refinishing. However, when this occurs precautions, as discussed above, should be taken to avoid further cracking.

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6. Eugene Goeb, *Common Field Problems*, Concrete Construction, October 1985.

Follow These Rules to Minimize Plastic Shrinkage Cracking

1. Dampen the subgrade and forms when conditions for high evaporation rates exist.
2. Prevent excessive surface moisture evaporation by providing fog sprays and erecting windbreaks.
3. Cover concrete with wet burlap or polyethylene sheets between finishing operations.
4. Use cooler concrete in hot weather and avoid excessively high concrete temperatures in cold weather.
5. Cure properly as soon as finishing has been completed.

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CIP 6 - Joints in Concrete Slabs on Grade

WHAT are Joints?

Concrete expands and shrinks with changes in moisture and temperature. The overall tendency is to shrink and this can cause cracking at an early age. Irregular cracks are unsightly and difficult to maintain but generally do not affect the integrity of concrete. Joints are simply pre-planned cracks. Joints in concrete slabs can be created by forming, tooling, sawing, and placement of joint formers.

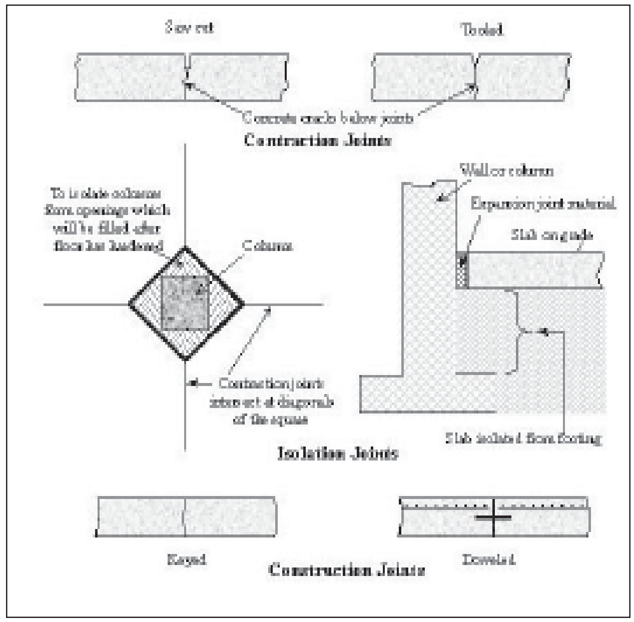
Some forms of joints are:

a. Contraction joints – are intended to create weakened planes in the concrete and regulate the location where cracks, resulting from dimensional changes, will occur.
b. Isolation or expansion joints – separate or isolate slabs from other parts of the structure, such as walls, footings, or columns; and driveways and patios from sidewalks, garage slabs, stairs, lightpoles and other points of restraint. They permit independent vertical and horizontal movement between adjoining parts of the structure and help minimize cracking when such movements are restrained.
c. Construction joints – are surfaces where two successive placements of concrete meet. They are typically placed at the end of a day's work but may be required when concrete placement is stopped for longer than the initial setting time of concrete. In slabs they may be designed to permit movement and/or to transfer load. The location of construction joints should be planned. It may be desirable to achieve bond and continue reinforcement through a construction joint.

WHY are Joints Constructed?

Cracks in concrete cannot be prevented entirely, but they can be controlled and minimized by properly designed joints. Concrete cracks because:

a. Concrete is weak in tension and, therefore, if its natural tendency to shrink is restrained, tensile stresses that exceed its tensile strength can develop, resulting in cracking.
b. At early ages, before the concrete dries out, most cracking is caused by temperature changes or by the slight contraction that takes place as the concrete sets and hardens. Later, as the concrete dries, it will shrink further and either additional cracks may form or preexisting cracks may become wider.



Joints provide relief from the tensile stresses, are easy to maintain and are less objectionable than uncontrolled or irregular cracks.

How to Construct Joints?

Joints must be carefully designed and properly constructed if uncontrolled cracking of concrete flatwork is to be avoided. The following recommended practices should be observed:

a. The maximum joint spacing should be 24 to 36 times the thickness of the slab. For example, in a 4-inch [100 mm] thick slab the joint spacing should be about 10 feet [3 m]. It is further recommended that joint spacing be limited to a maximum of 15 feet [4.5 m].

b. All panels should be square or nearly so. The length should not exceed 1.5 times the width. Avoid L-shaped panels.

c. For contraction joints, the joint groove should have a minimum depth of $^1/_4$ the thickness of the slab, but not less than 1 inch [25 mm]. Timing of jointing operations depends on the method used:
   - Preformed plastic or hard board joint strips are inserted into the concrete surface to the required depth before finishing.
   - Tooled joints must be run early in the finishing process and rerun later to ensure groove bond has not occurred.
   - Early-entry dry-cut joints are generally run 1 to 4 hours after completion of finishing, depending on the concrete's setting characteristics. These joints are typically not as deep as those obtained by the conventional saw-cut process, but should be a minimum of 1 inch [25 mm] in depth.
   - Conventional saw-cut joints should be run within 4 to 12 hours after the concrete has been finished.

d. Raveling during saw cutting is affected by the strength of the concrete and aggregate characteristics. If the joint edges ravel during sawing, it must be delayed. However, if delayed too long, sawing can become difficult and uncontrolled cracking may occur.

e. Use premolded joint filler such as asphalt-impregnated fiber sheeting, compressible foam strips, or similar materials for isolation joints to separate slabs from building walls or footings. At least 2 inches [50 mm] of sand over the top of a footing will also prevent bond to the footing.

f. To isolate columns from slabs, form circular or square openings, which will not be filled until after the floor has hardened. Slab contraction joints should intersect at the openings for columns. If square openings are used around columns, the square should be turned at 45 degrees so the contraction joints intersect at the diagonals of the square.

g. If the slab contains wire mesh, cut out alternate wires, or preferably discontinue the mesh, across contraction joints. Note that wire mesh will not prevent cracking. Mesh tends to keep the cracks and joints tightly closed.

h. Construction joints key the two edges of the slab together either to provide transfer of loads or to help prevent curling or warping of the two adjacent edges. Galvanized metal keys are sometimes used for interior slabs, however, a beveled 1 by 2 inch [25 by 50 mm] strip, nailed to bulkheads or form boards, can be used in slabs that are at least 5 inches [125 mm] thick to form a key which will resist vertical loads and movements. Keyed joints are not recommended for industrial floors. Metal dowels should be used in slabs that will carry heavy loads. Dowels must be carefully lined up and parallel or they may induce restraint and cause random cracking at the end of the dowel.

i. Joints in industrial floors subject to heavy traffic require special attention to avoid spalling of joint edges. Such joints should be filled with a material capable of supporting joint edges. Manufacturer's recommendations and performance records should be checked before use.

References

1. *Joints in Concrete Construction*, ACI 224.3R, American Concrete Institute, Farmington Hills, MI.
2. *Guide for Concrete Floor and Slab Construction*, ACI 302.1R, American Concrete Institute, Farmington Hills, MI.
3. *Slabs on Grade*, ACI Concrete Craftsman Series CCS-1, American Concrete Institute, Farmington Hills, MI.
4. *Joint Planning Primer*, Concrete Construction, August 1997.
5. Bruce A. Suprenant, *Sawcutting Joints in Concrete*, Concrete Construction, January 1995.

Follow These Rules for Proper Jointing

1. Plan exact location of all joints, including timing of contraction joint sawing before construction.
2. Provide isolation joints between slabs and columns, walls and footings, and at junctions of driveways with walks, curbs or other obstructions.
3. Provide contraction joints and joint filling materials as outlined in specifications.

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CIP 7 - Cracks in Concrete Basement Walls

WHAT Types of Cracks May Occur?

Cast-in-place concrete basements provide durable, high quality extra living space. At times undesirable cracks occur. They result from:

a. Temperature and drying shrinkage cracks. With few exceptions, newly placed concrete has the largest volume that it will ever have. Shrinkage tendency is increased by excessive drying and/or a significant drop in temperature that can lead to random cracking if steps are not taken to control the location of the cracks by providing control joints. When the footing and wall are placed at different times, the shrinkage rates differ and the footing restrains the shrinkage in the wall causing cracking. Lack of adequate curing practices can also result in cracking.

b. Settlement cracks. These occur from non-uniform support of footings or occasionally from expansive soils.

c. Other structural cracks. In basements these cracks generally occur during backfilling, particularly when heavy equipment gets too close to the walls.

d. Cracks due to lack of joints or improper jointing practices.

WHY do Basement Cracks Occur?

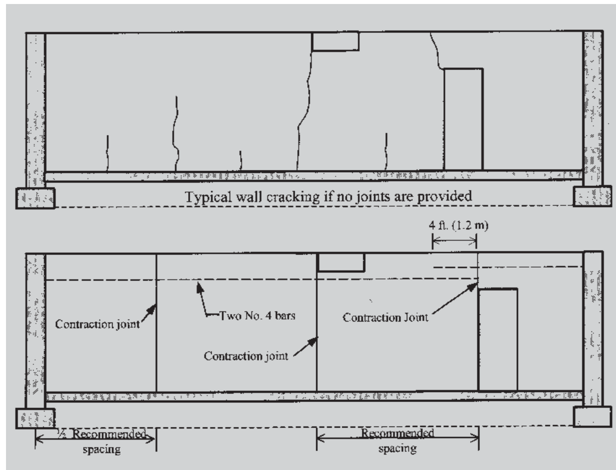
In concrete basement walls some cracking is normal. Most builders or third party providers offer limited warranties for basements. A typical warranty will require repair only when cracks leak or exceed the following:

	Crack Width	Vertical Displacement
Basement Walls	1/8" (3-mm)	–
Basement Floors	3/16" (12-mm)	1/8" (12-mm)
Garage Slabs	1/4" (12-mm)	1/4" (12-mm)

The National Association of Homebuilders requires repair or corrective action when cracks in concrete basements walls allow exterior water to leak into the basement.

If the following practices are followed the cracking is minimized:

a. Uniform soil support is provided.



Typical detail of joints in basement walls

b. Concrete is placed at a moderate slump - up to about 5 inches (125 mm) and excessive water is not added at the jobsite prior to placement.

c. Proper construction practices are followed.

d. Control joints are provided every 20 to 30 feet (6 to 9 m).

e. Backfilling is done carefully and, if possible, waiting until the first floor is in place in cold weather. Concrete gains strength at a slower rate in cold weather.

f. Proper curing practices are followed.

How to Construct Quality Basements?

Since the performance of concrete basements is affected by climate conditions, unusual loads, materials quality and workmanship, care should always be exercised in their design and construction. The following steps should be followed:

a. **Site conditions and excavation**. Soil investigation should be thorough enough to insure design and construction of foundations suited to the building site. The excavation should be to the level of the bottom of the footing. The soil or granular fill beneath the entire area of the basement should be well compacted by rolling, vibrating or tamping. Footings must bear on undisturbed soil.

b. **Formwork and reinforcement**. All formwork must be constructed and braced so that it can withstand the pressure of the plastic concrete. Reinforcement is effective in controlling shrinkage cracks and is especially beneficial where uneven side pressures against the walls may be expected. Observe state and local codes and guidelines for wall thickness and reinforcement.

c. **Joints**. Shrinkage and temperature cracking of basement walls can be controlled by means of properly located and formed joints. As a rule of thumb, in 8-ft. (2.5-m) high and 8-inch (200-mm) thick walls, vertical control joints should be provided at a spacing of about 30 times the wall thickness. These wall joints can be formed by nailing a 3/4-inch (20-mm) thick strip of wood, metal, plastic or rubber, beveled from 3/4 to 1/2 inch (20 to 12-mm) in width, to the inside of both interior and exterior wall forms. The depth of the grooves should be at least 1/4 the wall thickness. After the removal, the grooves should be caulked with a good quality joint filler. For large volume pours or with abrupt changes in wall thickness, bonded construction joints should be planned before construction. The construction joints may be horizontal or vertical. Wall reinforcement continues through a construction joint.

d. **Concrete**. In general, use concrete with a moderate slump up to 5 inches (125-mm). Avoid retempering with water prior to placing concrete. Concrete with a higher slump may be used providing the mixture is specifically designed to produce the required strength without excessive bleeding and/or segregation. Water reducing admixtures can be used for this purpose. In areas where the weather is severe and walls may be exposed to moisture and freezing temperatures air entrained concrete should be used.

e. **Placement and curing**. Place concrete in a continuous operation to avoid cold joints. If concrete tends to bleed and segregate a lower slump should be used and the concrete placed in the form every 20 or 30 feet around the perimeter of the wall. Higher slump concretes that do not bleed or segregate will flow horizontally for long distances and reduce the number of required points of access to the form. Curing should start immediately after finishing. Forms should be left in place five to seven days or as long as possible. If forms are removed after one day some premature drying can result at the surface of the concrete wall and may cause cracking. In general, the application of a liquid membrane-forming curing compound or insulated blankets immediately after removal of forms will help prevent drying and will provide better surface durability. (See CIP 11 on Curing). During cold weather, forms may be insulated or temporarily covered with insulating materials to conserve heat from hydration and avoid the use of an external source of heat. (See CIP 27 on Cold Weather Concreting). During hot dry weather, forms should be covered. Wet burlap, liquid membrane-forming curing compound sprayed at the required coverage or draping applied as soon as possible after the forms are removed. (See CIP 12 on Hot Weather Concreting).

f. **Waterproofing and drainage**. Spray or paint the exterior of walls with damp proofing materials or use waterproof membranes. Provide foundation drainage by installing drain tiles or plastic pipes around the exterior of the footing, then cover with clean granular fill to a height of at least 1 foot prior to backfilling. Water should be drained to lower elevations suitable to receive storm water run off.

g. **Backfilling and final grading**. Backfilling should be done carefully to avoid damaging the walls. Brace the walls or, if possible, have first floor in place before backfill. To drain the surface water away from the basement finish grade should fall off 1/2 to 1 inch per foot (40 to 80-mm per meter) for at least 8 to 10 feet (2.5 to 3 m) away from the foundation.

h. **Crack repair**. In general, epoxy injection, drypacking, or routing and sealing techniques can be used to repair stabilized cracks. Before repairing leaking cracks, the drainage around the structure should be checked and corrected if necessary. Details of these and other repair methods are provided in Reference 1. Active cracks should be repaired based on professional advice.

References

1. *Causes, Evaluation and Repair of Cracks*, ACI 224.1R, American Concrete Institute, Farmington Hills, MI.
2. *Joints in Concrete Construction*, ACI 224.3R, American Concrete Institute, Farmington Hills, MI.
3. *Residential Concrete*, National Association of Home Builders, National Association of Home Builders, Washington, DC.
4. *Residential Construction Performance Guidelines*, National Association of Home Builders, Washington, DC.
5. *Solid Concrete Basement Walls*, National Ready Mixed Concrete Association, Silver Spring, MD.

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CIP 8 - Discrepancies in Yield

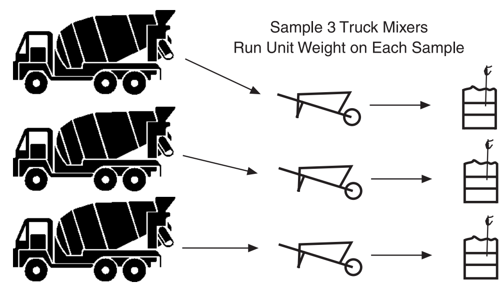
WHAT is Concrete Yield?

Concrete yield is defined as the volume of freshly mixed concrete from a known quantity of ingredients. Ready mixed concrete is sold on the basis of the volume of fresh, unhardened concrete-in cubic yards (yd^3) or cubic meters (m^3) as discharged from a truck mixer.

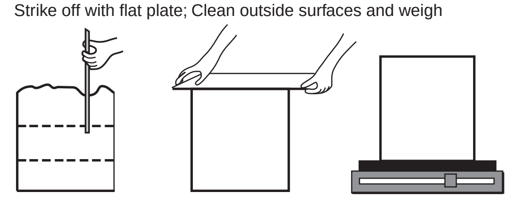
The basis for calculating the volume is described in the ASTM C 94, *Specification for Ready Mixed Concrete.* The volume of freshly mixed and unhardened concrete in a given batch is determined by dividing the total weight of the materials by the average unit weight or density of the concrete determined in accordance with ASTM C 138. Three unit weight tests must be made, each from a different truck.

ASTM C 94 notes: *It should be understood that the volume of hardened concrete may be, or appears to be, less than expected due to waste and spillage, over-excavation, spreading forms, some loss of entrained air, or settlement of wet mixtures, none of which are the responsibility of the producer.*

Further, the volume of hardened concrete in place may be about 2 percent less than its volume in a freshly mixed state due to reduction in air content, settlement and bleeding, decrease in volume of cement and water, and drying shrinkage.



ASTM C 138 - Test for Unit Weight
Fill unit weight container in 3 layers;
Rod each layer 25 times; tap sides with mallet;
Strike off with flat plate; Clean outside surfaces and weigh



3 Layers | Use Flat Plate | Weigh

$$\text{Unit Wt., lb/ft}^3\ (\text{kg/m}^3) = \frac{\text{Net concrete weight, lb (kg)}}{\text{Bucket Volume, ft}^3\ (\text{m}^3)}$$

$$\text{Avg. Unit Wt.} = \frac{(UW1 + UW2 + UW3)}{3},\ \text{lb/ft}^3\ (\text{kg/m}^3)$$

$$\text{Batch Yield, cu. yd.} = \frac{\text{Weight of Batch, lb.}}{27 \times \text{Avg. Unit Wt., lb/ft}^3}$$

$$\text{Batch Yield, m}^3 = \frac{\text{Weight of Batch, kg}}{\text{Avg. Unit Wt., kg/m}^3}$$

WHY do Yield Problems Occur?

Most yield complaints concern a perceived or real deficiency of concrete volume. Concerns about yield should be evaluated using unit weight measurements to calculate the yield. Apparent under-yield occurswhen insufficient concrete is ordered to fill the forms and to account for contingencies discussed below. If unit weight and yield calculations indicate an actual under-yield it should be corrected.

Apparent concrete shortages are sometimes caused for the following reasons:

a. Miscalculation of form volume or slab thickness when the actual dimensions exceed the assumed dimensions by a fraction of an inch. For example, a 1/8-inch (3-mm) error in a 4-inch (100-mm) slab would mean a shortage of 3 percent or 1 yd^3 in a 32-yd^3 (1 m^3 in a 32-m^3) order.

b. Deflection or distortion of the forms resulting from pressure exerted by the concrete.

c. Irregular subgrade, placement over granular fill, and settlement of subgrade prior to placement.

d. Over the course of a large job, the small amounts of concrete returned each day or used in mud sills or incidental footings.

An over-yield can be an indication of a problem if the excess concrete is caused by too much air or aggregate, or if the forms have not been properly filled.

Differences in batched weights of ingredients and air content in concrete, within the permitted tolerances, can result in discrepancies in yield.

HOW to Prevent Yield Discrepancies?

To prevent or minimize concrete yield problems:

a. Check concrete yield by measuring concrete unit weight in accordance with ASTM C 138 early in the job. Repeat these tests if a problem arises. Be sure that the scale is accurate, that the unit weight bucket is properly calibrated, that a flat plate is used for strike off and that the bucket is cleaned prior to weighing. Concrete yield in cubic feet (m^3) is total batch weight in pounds (kg) divided by unit weight in pounds per cubic foot (kg/m^3). The total batch weight is the sum of the weights of all ingredients from the batch ticket. As a rough check, the mixer truck can be weighed empty and full. The difference is the total batch weight.

b. Measure formwork accurately. Near the end of large pours, carefully measure the remaining volume so that the order for the last 2 or 3 trucks can be adjusted to provide the required quantity of concrete. This can prevent waiting for an extra 1/2 yd^3 after the plant has closed or the concrete trucks have been scheduled for other jobs. Order sufficient quantity of concrete to complete the job and reevaluate the amount required towards the end of the pour. Disposal of returned concrete has environmental and economic consequences to the concrete producer.

c. Estimate extra concrete needed for waste and increased placement dimensions over nominal dimensions. Include an allowance of 4 to 10 percent over plan dimensions for waste, over-excavation and other causes. Repetitive operations and slip form operations permit more accurate estimates of the amount of concrete that will be needed. On the other hand, sporadic operations involving a combination of concrete uses such as slabs, footings, walls, and as incidental fill around pipes, etc., will require a bigger allowance for contingencies.

d. Construct and brace forms to minimize deflection or distortion.

e. For slabs on grade accurately finish and compact the subgrade to the proper elevation.

References

1. ASTM C 94, *Standard Specification for Ready Mixed Concrete*, American Society for Testing and Materials, West Conshohocken, PA.
2. ASTM C 138, *Standard Test Method for Unit Weight, Yield and Air Content (Gravimetric) of Concrete*, American Society for Testing and Materials.
3. *Ready Mixed Concrete*, Gaynor, R.D. NRMCA Publication 186, NRMCA, Silver Spring, Maryland.
4. *No Minus Tolerance on Yield*, Malisch, W. R. and Suprenant, B. A., Concrete Producer, May 1998
5. *Causes for Variation in Concrete Yield*, Suprenant, B. A., The Concrete Journal, March 1994
6. *An Analysis of Factors Influencing Concrete Pavement Cost*, by Harold J. Halm, Portland Cement Association Skokie, Illinois.

Follow These Rules to Avoid Under-Yield

1. Measure volume needed accurately. Reevaluate required volume towards the end of the pour and inform the concrete producer.
2. Estimate waste and potential increased thickness – order more than required by at least 4 to 10 percent.
3. To check yield use the ASTM C 138 unit weight test method on three samples from three different loads – yield is the total batch weight divided by the average unit weight or density.

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CIP 9 - Low Concrete Cylinder Strength

WHAT Constitutes Low Cylinder Strength?

Strength test results of concrete cylinders are used as the basis of acceptance of ready mixed concrete when a strength requirement is specified. Cylinders are molded from a sample of fresh concrete, cured in standard conditions and tested at a particular age, as indicated in the specification, usually at 28 days. Procedures must be in accordance with ASTM standards. The average strength of a set of 2 or 3 cylinders made from the same concrete sample and tested at 28 days constitutes one test. In some cases cylinders are tested at 7 days to get an early indication of the potential strength, but these test results are not to be used for concrete acceptance. Cylinders used for acceptance of concrete should not be confused with field-cured cylinders, which are made to check early-age strength in the structure to strip forms and continue construction activity.

The ACI Building Code, ACI 318, and the Standard Specifications for Structural Concrete, ACI 301, recognize that when mixtures are proportioned to meet the requirements of the standards, low strength results will occur about once or twice in 100 tests due to normal variability.

Under these provisions, for specified strength less than 5000 psi (35 MPa), concrete is acceptable and complies with the specification if:

a. No single test is lower than the specified strength by more than 500 psi (3.5 MPa), and
b. The average of three consecutive tests equals or exceeds the specified strength.

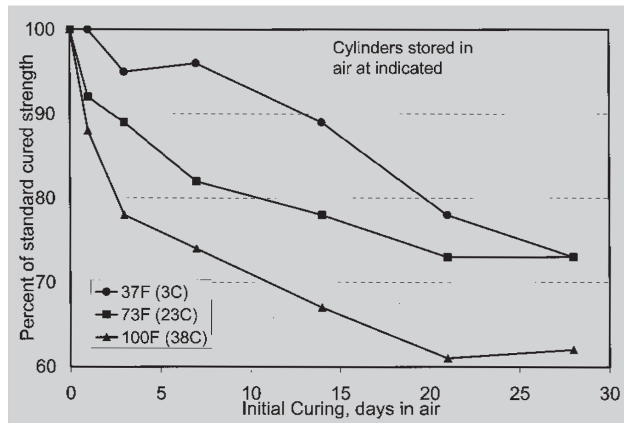
See the example in the table. If an average of three consecutive tests in sequence falls below the specified strength, steps must be taken to increase the strength of the concrete. If a single test falls more than 500 psi (3.5 MPa) below the specified strength, an investigation should be made to ensure structural adequacy of that portion of the structure; and again, steps taken to increase the strength level.

WHY are Compressive Tests Low?

Two major reasons are:

a. Improper cylinder handling, curing and testing - found to contribute in the majority of low strength results, and
b. Reduced concrete strength due to an error in production, or the addition of too much water to the concrete on the job due to delays in placement or requests for wet concrete. High air content can also be a cause of low strength.

In the event of low compressive strength test results, collect all test reports and analyze the results before taking action. Look at the pattern of strength results. Does the sequence actually violate compliance with the specification as discussed above? Do the test reports give any clue to the cause? The strength range of two or three cylinders prepared from the same sample should rarely exceed 8.0% or 9.5% of the average, respectively. Look at the slump, air content, concrete and ambient temperatures, number of days cylinders were left in the field, procedures used for initial curing in the field and subsequent curing in the lab and any reported cylinder defects.



Effect of Non-Standard Curing on Compressive Strength (Ref 5)

If the deficiency justifies investigation, first verify testing accuracy and then compare the structural requirements with the measured strength. If testing is deficient or if strength is greater than

Acceptance of Concrete on Compressive Strength
4000 psi Specified Strength

Test No.	Individual Cyl. No. 1	Individual Cyl. No. 2	Average (Test)	Average of 3 Consecutive
		Acceptable Example		
1	4110	4260	4185	— —
2	3840	4080	3960	— —
3	4420	4450	4435	4193
4	3670	3820	3745	4047
5	4620	4570	4595	4258
		Low Strength Example		
1	3620	3550	3585	— —
2	3970	4060	4015	— —
3	4080	4000	4040	3880*
4	4860	4700	4780	4278
5	3390	3110	3250†	4023

* Average of three consecutive low.
† One test more than 500 psi low.

that actually needed in that portion of the structure, there is little point in investigating the in-place strength. However, if procedures conform to the standards and the strength as specified is required for the structural capacity of the member in question, further investigation of the in-place concrete may be required. (See CIP- 10 on Strength of In-Place Concrete.)

Have testing procedures been conducted in accordance with the ASTM standards? Minor deficiencies in curing cylinders in mild weather will probably not affect strength much, but if major violations are discovered, large reductions in strength can occur. Almost all deficiencies in handling and testing cylinders will lower strength. A number of violations may combine to cause significant reductions in measured strength. Some of the more significant factors are improperly finished surfaces, initial curing over 80°F (27°C); frozen cylinders; extra days in the field; impact during transportation; delay in curing at the lab; improper caps; and insufficient care in breaking cylinders.

The laboratory should be held responsible for deficiencies in its procedures. Use of certified field-testing technicians and laboratory personnel is essential; construction workers untrained in concrete testing must not make and handle cylinders. All labs should meet ASTM C 1077 criteria for laboratories testing concrete and concrete aggregates and be inspected by the Cement and Concrete Reference Laboratory (CCRL) laboratory inspection or an equivalent program. Field testing personnel must have a current ACI Grade I Field Testing Technician certification or equivalent. Laboratory personnel should have the ACI Grade I and II Laboratory Testing Technician and/or the ACI Strength Testing Certification, or equivalent.

HOW to Make Standard Cylinder Tests?

All of the detailed steps from obtaining a sample, through molding, curing, transporting, testing and reporting cylinder testing are important. The following are critical procedures in the proper application of the ASTM Standards for strength tests of field-made, laboratory-cured cylinders:

a. Sample concrete falling from chute in two increments, from the middle part of the load, after some has been discharged.
b. Transport sample to the location of curing for the first day.
c. Remix the sample to ensure homogeneity.
d. Use molds conforming to standards.
e. Using a standard rod or vibrator, consolidate concrete in two or three equal layers, as required, and tap sides of the mold to close rod holes.
f. Finish tops smooth and level to allow thin caps.
g. If necessary, move cylinders immediately after molding; support the bottom.
h. For initial curing of cylinders at the jobsite during the first 24 to 48 hours, store cylinders in a moist environment maintained at 60 to 80°F (16 to 27°C). If feasible, immerse the molded cylinders in water maintained within this temperature range. Curing boxes without temperature controls can overheat and result in lower strengths.
i. If the cylinders are stored exposed to the environment, keep out of direct sunlight and protect from loss of moisture.
j. Carefully transport one day-old cylinders to the laboratory; handle gently.
k. At the laboratory, demold the cylinders, transfer identifying marking and promptly place in moist curing at 73±3°F (23±2°C).
l. Cure cylinders in the laboratory in accordance with ASTM C 31; maintain water on cylinder surfaces at all times.
m. Determine the mass of the cylinder and record it. This information is useful in troubleshooting low strength problems.
n. Caps on cylinders must be flat and the average thickness less than 1/4-inch (6-mm) and preferably less than 1/8-inch (3-mm). This is especially significant when testing concrete with strength exceeding 7000 psi (48 MPa).
o. Use minimum 5000 psi (35 MPa) capping material. Restrict the reuse of sulfur capping compound.
p. Wait at least 2 hours and preferably longer for sulfur caps to harden. Sulfur caps aged for 1 to 2 days often result in higher strength, especially when testing concrete with strength exceeding 5000 psi (35 MPa).
q. When using neoprene pad caps, ensure that the appropriate Durometer hardness is used for the strength level tested; the pad caps have been qualified for use; pads are not worn and the permitted number of reuses have not been exceeded; see ASTM C 1231. Worn pads will reduce the measured strength.
r. Ensure that the testing machine is calibrated.
s. Measure cylinder diameter and check cap planeness.
t. Center cylinder on the testing machine and use proper loading rate.
u. Break the cylinder to complete failure. Observe failure pattern; vertical cracks through the cap or a chip off the side indicate improper load distribution.

Test reports must be promptly distributed to the concrete producer, as well as the contractor and engineer. This is essential to the timely resolution of problems.

References

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3. *Standard Specification for Structural Concrete*, ACI 301, American Concrete Institute, Farmington Hills, MI.
4. *In-Place Concrete Strength Evaluation-A Recommended Practice*. NRMCA Publication 133, NRMCA, Silver Spring, MD.
5. *Effect of Curing Condition on Compressive Strength of Concrete Test* Specimens, NRMCA Publication 53, NRMCA Silver Spring, MD.
6. *Review of Variables that Influence Measured Concrete Compressive Strength*, David N. Richardson, NRMCA Publication 179, NRMCA, Silver Spring, MD.
7. *Low Strength Tests?* Maybe Not! E.O. Goeb, Concrete Products, December 1992.
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CIP 10 - Strength of In-Place Concrete

WHAT is the Strengthof In-Place Concrete?

Concrete structures are designed to carry dead and live loads during construction and in service. Samples of concrete are obtained during construction and standard ASTM procedures are used to measure the potential strength of the concrete as delivered. Cylinders are molded and cured at 60 to 80°F (17 to 27°C) for one day and then moist cured in the laboratory until broken in compression, normally at an age of 7 and 28 days. The in-place strength of concrete will not be equivalent to that measured on standard cylinders. Job practices for handling, placing, consolidation, and curing concrete in structures are relied upon to provide an adequate percentage of that potential strength in the structure. Structural design principles recognize this and the ACI Building Code, ACI 318, has a process of assuring the structural safety of the concrete construction.

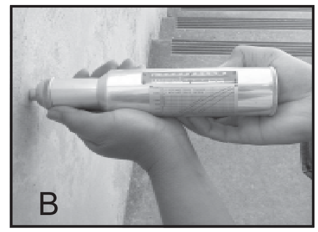
Means of measuring, estimating or comparing the strength of in-place concrete include: rebound hammer, penetration probe, pullouts, cast-in-place cylinders, tests of drilled cores, and load tests of the structural element.

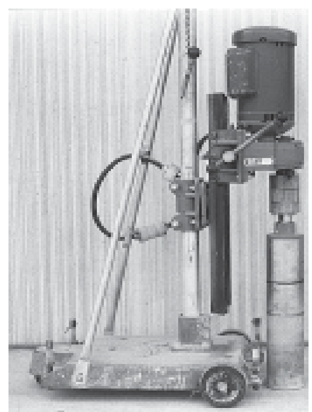
Cores drilled from the structure are one of the means of evaluating whether the structural capacity of a concrete member is adequate and ACI 318 provides some guidance on this evaluation. Drilled cores test lower than properly made and tested standard molded 6 x 12 inch (150 x 300-mm) cylinders. This applies to all formed structural concrete. Exceptions may occur for cores from concrete cast against an absorptive subgrade or cores from lean, low strength mass concrete. The ACI Building Code recognizes that under current design practices, concrete construction can be considered structurally adequate if the average of three cores from the questionable region is equal to or exceeds 85 percent of specified strength, f'_c with no single core less than 75 percent of f'_c.

WHY Measure In-Place Strength?

Tests of in-place concrete may be needed when standard cylinder strengths are low and not in compliance with the specification as outlined in ACI 318. However, do not investigate in-place without first checking to be sure that: the concrete strengths actually failed to meet the specification provisions, low strengths are not attributable to faulty testing practices, or the specified strength is really needed. (See CIP-9 on Low Concrete Cylinder Strength) In many cases, the concrete can be accepted for the intended use without in-place strength testing.

There are many other situations that may require the investigation of in-place strength. These include: shore and form removal, post-tensioning, or early load application; investigation of damage due to freezing, fire, or adverse curing exposure; evaluation of older structures; and when a lower design strength concrete is placed in a member by mistake. When cores or other in-place tests fail to assure structural adequacy, additional curing of the structure may provide the necessary strength. This is particularly possible with concrete containing slow strength-gaining cement, fly ash, or slag.





A - Penetration Resistance Test (ASTM C 803)

B - Rebound Test (ASTM C 805)

C - Core Test (ASTM C 42)

HOW to Make Standard Cylinder Tests?

If only one set of cylinders is low, often the question can be settled by comparing rebound hammer or probe results on concrete in areas represented by acceptable cylinder results. Where the possibility of low strength is such that large portions need to be investigated, a well-organized study will be needed. Establish a grid and obtain systematic readings including good and questionable areas. Tabulate the hammer or probe readings. If areas appear to be low, drill cores from both low and high areas. If the cores confirm the hammer or probe results, the need for extensive core tests is greatly reduced.

Core Strength, ASTM C 42 - If core drilling is necessary observe these precautions:

a. Test a minimum of 3 cores for each section of questionable concrete;
b. Obtain $3^1/_2$ in. (85 mm) minimum diameter cores. Obtain larger cores for concrete with over 1 in. (25.0 mm) size aggregate;
c. Try to obtain a length at least $1^1/_2$ times the diameter (L/D ratio);
d. Trim to remove steel provided the minimum $1^1/_2$ L/D ratio can be maintained;
e. Trim ends square with an automatic feed diamond saw;
f. When testing, keep cap thickness under 1/8 in. (3 mm);
g. Use high strength capping material; neoprene pad caps should not be used;
h. Check planeness of caps and bearing blocks;
i. Do not drill cores from the top layers of columns, slabs, walls, or footings, which will be 10 to 20 percent weaker than cores from the mid or lower portions; and
j. Test cores after drying for 7 days if the structure is dry in service; otherwise soak cores 40 hours prior to testing. Review the recommendations for conditioning cores in current versions of ACI 318 and ASTM C 42.

Probe Penetration Resistance, ASTM C 803 - Probes driven into concrete can be used to study variations in concrete quality:

a. Different size probes or a change in driving force may be necessary for large differences in strength or unit weight;
b. Accurate measurement of the exposed length of the probe is required;
c. Probes should be spaced at least 7 in. apart and not be close to the edge of the concrete;
d. Probes not firmly embedded in the concrete should be rejected; and
e. Develop a strength calibration curve for the materials and conditions under investigation.

Rebound Hammer, ASTM C 805 - Observe these precautions:

a. Wet all surfaces for several hours or overnight because drying affects rebound number;
b. Don't compare readings on concrete cast against different form materials, concrete of varying moisture content, readings from different impact directions, on members of different mass, or results using different hammers;
c. Don't grind off the surface unless it is soft, finished or textured;
d. Test structural slabs from the bottom; and
e. Do not test frozen concrete.

Advance Planning - When it is known in advance that in-place testing is required, such as for shore and form removal, other methods can be considered such as: cast-in-place, push-out cylinders and pullout strength measuring techniques covered by ASTM C 873 and C 900.

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1982, 1989 AND 2000

Concrete in Practice

What, why & how?

NRMCA

CIP 11 - Curing In-Place Concrete

WHAT is Curing?

Curing is the maintaining of an adequate **moisture** content and **temperature** in concrete at early ages so that it can develop properties the mixture was designed to achieve. Curing begins immediately after placement and finishing so that the concrete may develop the desired strength and durability.

Without an adequate supply of moisture, the cementitious materials in concrete cannot react to form a quality product. Drying may remove the water needed for this chemical reaction called **hydration** and the concrete will not achieve its potential properties.

Temperature is an important factor in proper curing, since the rate of hydration, and therefore, strength development, is faster at higher temperatures. Generally, concrete temperature should be maintained above 50°F (10°C) for an adequate rate of strength development. Further, a uniform temperature should be maintained through the concrete section while it is gaining strength to avoid thermal cracking.

For exposed concrete, relative humidity and wind conditions are also important; they contribute to the rate of moisture loss from the concrete and could result in cracking, poor surface quality and durability. Protective measures to control evaporation of moisture from concrete surfaces before it sets are essential to prevent plastic shrinkage cracking (See CIP 5).

WHY Cure?

Several important reasons are:

a. **Predictable strength gain**. Laboratory tests show that concrete in a dry environment can lose as much as 50 percent of its potential strength compared to similar concrete that is moist cured. Concrete placed under high temperature conditions will gain early strength quickly but later strengths may be reduced. Concrete placed in cold weather will take longer to gain strength, delaying form removal and subsequent construction.

b. **Improved durability**. Well-cured concrete has better surface hardness and will better withstand surface wear and abrasion. Curing also makes concrete more watertight, which prevents moisture and water-borne chemicals from entering into the concrete, thereby increasing durability and service life.

c. **Better serviceability and appearance**. A concrete slab that has been allowed to dry out too early will have a soft surface with poor resistance to wear and abrasion. Proper curing reduces crazing, dusting and scaling.

Application of liquid membrane-forming compound with hand sprayer.

Slab on grade covered with waterproof paper for curing.

HOW to Cure?

Moisture Requirements for Curing - Concrete should be protected from losing moisture until final finishing using suitable methods like wind breaks, fogger sprays or misters to avoid plastic shrinkage cracking. After final finishing the concrete surface must be kept continuously wet or sealed to prevent evaporation for a period of at least several days after finishing. See the table for examples.

Systems to keep concrete wet include:

a. Burlap or cotton mats and rugs used with a soaker hose or sprinkler. Care must be taken not to let the coverings dry out and absorb water from the concrete. The edges should be lapped and the materials weighted down so they are not blown away.

b. Straw that is sprinkled with water regularly. Straw can easily blow away and, if it dries, can catch fire. The layer of straw should be 6 inches thick, and should be covered with a tarp.

c. Damp earth, sand, or sawdust can be used to cure flatwork, especially floors. There should be no organic or iron-staining contaminants in the materials used.

d. Sprinkling on a continuous basis is suitable provided the air temperature is well above freezing. The concrete should not be allowed to dry out between soakings, since alternate wetting and drying is not an acceptable curing practice.

e. Ponding of water on a slab is an excellent method of curing. The water should not be more than 20°F (11°C) cooler than the concrete and the dike around the pond must be secure against leaks.

Moisture retaining materials include:

a. Liquid membrane-forming curing compounds must conform to ASTM C 309. Apply to the concrete surface about one hour after finishing. Do not apply to concrete that is still bleeding or has a visible water sheen on the surface. While a clear liquid may be used, a white pigment will provide reflective properties and allow for a visual inspection of coverage. A single coat may be adequate, but where possible a second coat, applied at right angles to the first, is desirable for even coverage. If the concrete will be painted, or covered with vinyl or ceramic tile, then a liquid compound that is non-reactive with the paint or adhesives must be used, or use a compound that is easily brushed or washed off. On floors, the surface should be protected from the other trades with scuff-proof paper after the application of the curing compound.

b. Plastic sheets - either clear, white (reflective) or pigmented. Plastic should conform to ASTM C 171, be at least 4 mils thick, and preferably reinforced with glass fibers. Dark colored sheets are recommended when ambient temperatures are below 60°F (15°C) and reflective sheets should be used when temperatures exceed 85°F (30°C). The plastic should be laid in direct contact with the concrete surface as soon as possible without marring the surface. The edges of the sheets should overlap and be fastened with waterproof tape and then weighted down to prevent the wind from getting under the plastic. Plastic can make dark streaks wherever a wrinkle touches the concrete, so plastic should not be used on concretes where appearance is important. Plastic is sometimes used over wet burlap to retain moisture.

c. Waterproof paper - used like plastic sheeting, but does not mar the surface. This paper generally consists of two layers of kraft paper cemented together and reinforced with fiber. The paper should conform to ASTM C 171.

Note that products sold as evaporation retardants are used to reduce the rate of evaporation from fresh concrete surfaces before it sets to prevent plastic shrinkage cracking. These materials should not be used for final curing.

Example Minimum Curing Period to Achieve 50% of Specified Strength*

Type I Cement	Type II Cement	Type III Cement
Temperature—50°F (10°C)		
6 days	9 days	3 days
Temperature—70°F (21°C)		
4 days	6 days	3 days

*Values are approximate and based on cylinder strength tests. Specific values can be established for specific materials and mixtures. From Ref. 7.

Control of temperature:

In cold weather do not allow concrete to cool faster than a rate of 5°F (3°C) per hour for the first 24 hours. Concrete should be protected from freezing until it reaches a compressive strength of at least 500 psi (3.5 MPa) using insulating materials. Curing methods that retain moisture, rather than wet curing, should be used when freezing temperatures are anticipated. Guard against rapid temperature changes after removing protective measures. Guidelines are provided in Reference 7.

In hot weather, higher initial curing temperature will result in rapid strength gain and lower ultimate strengths. Water curing and sprinkling can be used to achieve lower curing temperatures in summer. Day and night temperature extremes that allow cooling faster than 5°F (3°C) per hour during the first 24 hours should be protected against.

References

1. *Effect of Curing Condition on Compressive Strength of Concrete Test Specimens*, NRMCA Publication No. 53, National Ready Mixed Concrete Association, Silver Spring, MD.
2. *How to Eliminate Scaling*, Concrete International, February 1980. American Concrete Institute, Farmington Hills, MI.
3. ASTM C 309, *Specification for Liquid Membrane Forming Compounds for Curing Concrete*, American Society for Testing Materials, West Conshohocken, PA.
4. ASTM C 171, *Specification for Sheet Materials for Curing Concrete*, American Society for Testing Materials, West Conshohocken, PA.
5. *Standard Practice for Curing Concrete*, ACI 308, American Concrete Institute, Farmington Hills, MI.
6. *Standard Specification for Curing Concrete*, ACI 308.1, American Concrete Institute, Farmington Hills, MI.
7. *Cold Weather Concreting*, ACI 306R, American Concrete Institute, Farmington Hills, MI.

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CIP 12 - Hot Weather Concreting

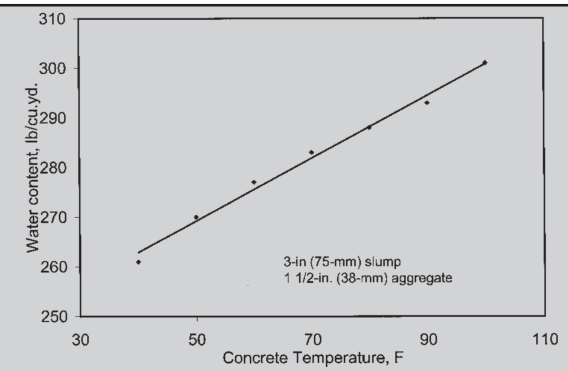
WHAT is Hot Weather?

Curing is the maintaining of an adequate **moisture** content and **temperature** in concrete at early ages so that it can develop properties the mixture was designed to achieve. Curing begins immediately after placement and finishing so that the concrete may develop the desired strength and durability.

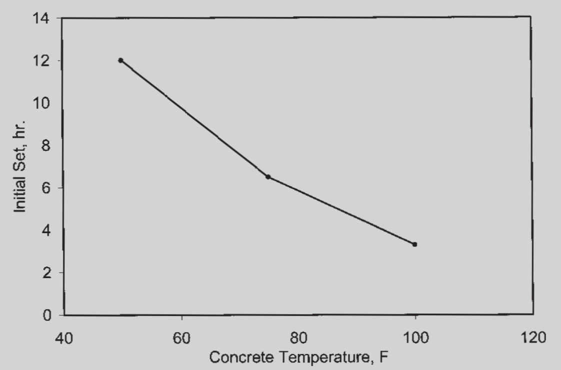
Without an adequate supply of moisture, the cementitious materials in concrete cannot react to form a quality product. Drying may remove the water needed for this chemical reaction called **hydration** and the concrete will not achieve its potential properties.

Temperature is an important factor in proper curing, since the rate of hydration, and therefore, strength development, is faster at higher temperatures. Generally, concrete temperature should be maintained above 50°F (10°C) for an adequate rate of strength development. Further, a uniform temperature should be maintained through the concrete section while it is gaining strength to avoid thermal cracking.

For exposed concrete, relative humidity and wind conditions are also important; they contribute to the rate of moisture loss from the concrete and could result in cracking, poor surface quality and durability. Protective measures to control evaporation of moisture from concrete surfaces before it sets are essential to prevent plastic shrinkage cracking (See CIP 5).



Effect of temperature on water requirement of concrete (Ref 1)



Effect of temperature on concrete setting time (Ref 1)

WHY Consider Hot Weather?

Several important reasons are:

a. **Predictable strength gain**. Laboratory tests show that concrete in a dry environment can lose as much as 50 percent of its potential strength compared to similar concrete that is moist cured. Concrete placed under high temperature conditions will gain early strength quickly but later strengths may be reduced. Concrete placed in cold weather will take longer to gain strength, delaying form removal and subsequent construction.

b. **Improved durability**. Well-cured concrete has better surface hardness and will better withstand surface wear and abrasion. Curing also makes concrete more watertight, which prevents moisture and water-borne chemicals from entering into the concrete, thereby increasing durability and service life.

c. **Better serviceability and appearance**. A concrete slab that has been allowed to dry out too early will have a soft surface with poor resistance to wear and abrasion. Proper curing reduces crazing, dusting and scaling.

HOW to Cure?

Moisture Requirements for Curing - Concrete should be protected from losing moisture until final finishing using suitable methods like wind breaks, fogger sprays or misters to avoid plastic shrinkage cracking. After final finishing the concrete surface must be kept continuously wet or sealed to prevent evaporation for a period of at least several days after finishing. See the table for examples.

Systems to keep concrete wet include:

a. Burlap or cotton mats and rugs used with a soaker hose or sprinkler. Care must be taken not to let the coverings dry out and absorb water from the concrete. The edges should be lapped and the materials weighted down so they are not blown away.

b. Straw that is sprinkled with water regularly. Straw can easily blow away and, if it dries, can catch fire. The layer of straw should be 6 inches thick, and should be covered with a tarp.

c. Damp earth, sand, or sawdust can be used to cure flatwork, especially floors. There should be no organic or iron-staining contaminants in the materials used.

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Moisture retaining materials include:

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Control of temperature:

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In hot weather, higher initial curing temperature will result in rapid strength gain and lower ultimate strengths. Water curing and sprinkling can be used to achieve lower curing temperatures in summer. Day and night temperature extremes that allow cooling faster than 5°F (3°C) per hour during the first 24 hours should be protected against.

References

1. *Effect of Curing Condition on Compressive Strength of Concrete Test Specimens*, NRMCA Publication No. 53, National Ready Mixed Concrete Association, Silver Spring, MD.
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7. *Cold Weather Concreting*, ACI 306R, American Concrete Institute, Farmington Hills, MI.

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Concrete in Practice

What, why & how?

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CIP 13 - Concrete Blisters

WHAT are Blisters?

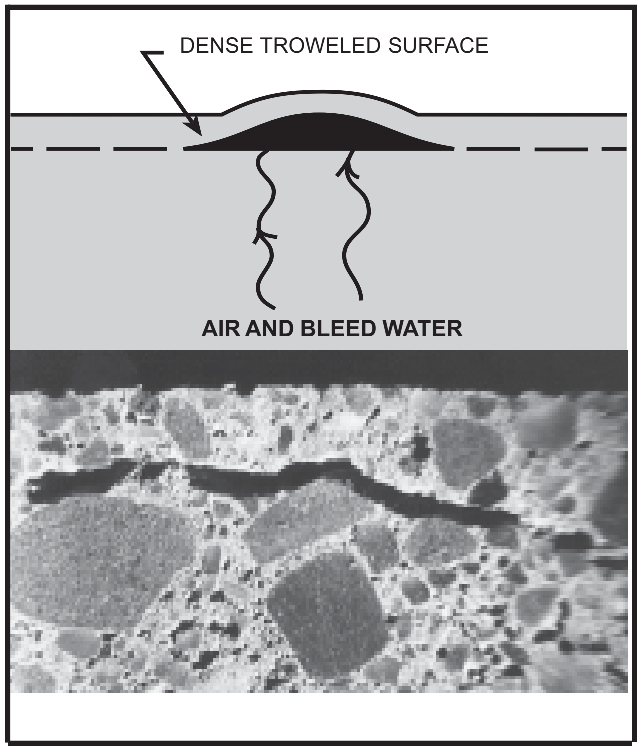
Blisters are hollow, low-profile bumps on the concrete surface, typically from the size of a dime up to 1 inch (25 mm), but occasionally even 2 or 3 inches (50 – 75 mm) in diameter. A dense troweled skin of mortar about $^{1}/_{8}$ in. (3 mm) thick covers an underlying void that moves around under the surface during troweling. Blisters may occur shortly after the completion of finishing operation. In poorly lighted areas, small blisters may be difficult to see during finishing and may not be detected until they break under traffic.

WHY do Blisters Form?

Blisters may form on the surface of fresh concrete when either bubbles of entrapped air or bleed water migrate through the concrete and become trapped under the surface, which has been sealed prematurely during the finishing operations. These defects are not easily repaired after concrete hardens.

Blisters are more likely to form if:

1. Insufficient or excessive vibration is employed. Insufficient vibration prevents the entrapped air from being released and excessive use of vibrating screeds works up a thick mortar layer on the surface.
2. An improper tool is used for floating the surface or it is used improperly. The surface should be tested to determine which tool, whether it be wood or magnesium bull float, does not seal the surface. The floating tool should be kept as flat as possible.
3. Excessive evaporation of bleed water occurs and the concrete appears ready for final finishing operations (premature finishing), when, in fact, the underlying concrete is still releasing bleed water and entrapped air. High rate of bleed water evaporation is especially a problem during periods of high ambient temperatures, high winds and/or low humidity.
4. Entrained air is used or is higher than normal. Rate of bleeding and quantity of bleed water is greatly reduced in air-entrained concrete giving the appearance that the concrete is ready to float and further finish causing premature finishing.
5. The subgrade is cooler than concrete. The top surface sets faster than the concrete in the bottom and the surface appears ready to be floated and further finished.
6. The slab is thick and it takes a longer time for the entrapped air and bleed water to rise to the surface.
7. The concrete is cohesive or sticky from higher content of cementitious materials or excessive fines in the sand. These mixtures also bleed less



Concrete Blister

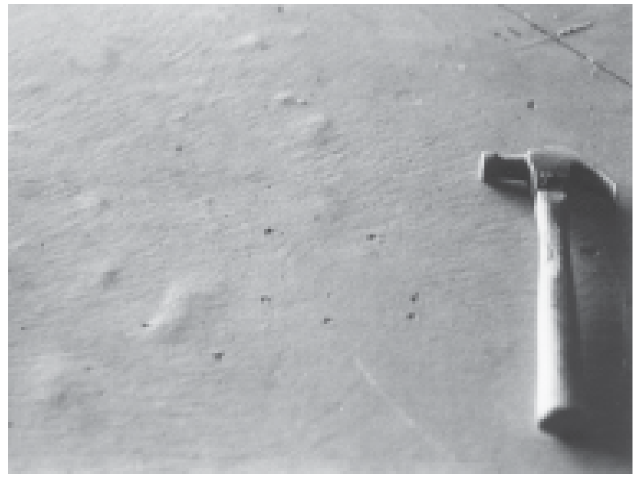
and at a slower rate. Concrete mixtures with lower contents of cementitious materials bleed rapidly for a shorter period, have higher total bleeding and tend to delay finishing.

8. A dry shake is prematurely applied, particularly over air-entrained concrete.
9. The slab is placed directly on top of a vapor retarder or an impervious base, preventing bleed water from being absorbed by the subgrade.

HOW To Prevent Blisters?

The finisher should be wary of a concrete surface that appears to be ready for final finishing before it would normally be expected. Emphasis in finishing operations should be on placing, striking off and bull floating the concrete as rapidly as possible and without working up a layer of mortar on the surface. After these operations are completed, further finishing should be delayed as long as possible and the surface covered with polyethylene or otherwise protected from evaporation. If conditions for high evaporation rates exist, place a cover on a small portion of the slab to judge if the concrete is still bleeding. In initial floating, the float blades should be flat to avoid densifying the surface too early. Use of an accelerating admixture or heated concrete often prevents blisters in cool weather. It is recommended that non-air entrained concrete be used in interior slabs and that air entrained concrete not be steel troweled.

If blisters are forming, try to either flatten the trowel blades or tear the surface with a wood float and delay finishing as long as possible. Under conditions causing rapid evaporation, slow evaporation by using wind breaks, water misting of the surface, evaporation retarders, or a cover (polyethylene film or wet burlap) between finishing operations. Further recommendations are given in ACI 302.1R and ACI 305.



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7. *Finishing*, Concrete Construction, August 1976, p. 369.
8. *Finishing Problems and Surface Defects in Flatwork*, Concrete Construction, April 1979.

Follow These Rules to Avoid Blisters

1. Do not seal surface before air or bleed water from below have had a chance to escape.
2. Avoid dry shakes on air-entrained concrete.
3. Use heated or accelerated concrete to promote even setting throughout the depth of the slab in cooler weather.
4. Do not place slabs directly on vapor retarders. If vapor retarders are essential (CIP 28) take steps to avoid premature finishing.
5. Protect surface from premature drying and evaporation.
6. Do not use a jitterbug or excessive vibration such as a vibratory screed on slumps over 5 inches (125 mm).
7. Air entrained concrete should not be steel troweled. If required by specifications, extreme caution should be exercised when timing the finishing operation.

1983, 2001, 2005

CIP 14 - Finishing Concrete Flatwork

WHAT is Finishing?

Finishing is the operation of creating a concrete surface of a desired texture, smoothness and durability. The finish can be strictly functional or decorative.

WHY Finish Concrete?

Finishing makes concrete attractive and serviceable. The final texture, hardness, and joint pattern on slabs, floors, sidewalks, patios, and driveways depend on the concrete's end use. Warehouse or industrial floors usually have greater durability requirements and need to be flat and level, while other interior floors that are covered with floor coverings do not have to be as smooth and durable. Exterior slabs must be sloped to carry away water and must provide a texture that will not be slippery when wet.

HOW to Place Concrete?

Prior to the finishing operation, concrete is placed, consolidated and leveled. These operations should be carefully planned. Skill, knowledge and experience are required to deal with a variety of concrete mixtures and field conditions. Having the proper manpower and equipment available, and timing the operations properly for existing conditions is critical. A slope is necessary to avoid low spots and to drain water away from buildings.

Complete all subgrade excavation and compaction, formwork, and placement of mesh, rebars or other embedments as required prior to concrete delivery. Delays after the concrete arrives create problems and can reduce the final quality of flatwork.

General guidelines for placing and consolidating concrete are:

a. A successful job depends on selecting the correct concrete mixture for the job. Consult your Ready Mixed Concrete Producer. Deposit concrete as near as possible to its final location, either directly in place from the truck chute or use wheelbarrows, buggies or pumps. Avoid adding excessive water to increase the concrete's slump. Start at the far end placing concrete into previously placed concrete and work towards the near end. On a slope, use concrete with a stiffer consistency (lower slump) and work up the slope.

Finishing Concrete Flatwork

b. Spread the concrete using a short-handled, square-ended shovel, or a come-along. Never use a garden rake to move concrete horizontally. This type of rake causes segregation.

c. All concrete should be well consolidated. For small flatwork jobs, pay particular attention to the edges of the forms by tamping the concrete with a spade or piece of wood. For large flatwork jobs, consolidation is usually accomplished by using a vibrating screed or internal vibrator.

d. When manually striking off and leveling the concrete, use a lumber or metal straightedge (called a screed). Rest the screed on edge on the top of the forms, tilt it forward and draw it across the concrete with a slight sawing motion. Keep a little concrete in front of the screed to fill in any low spots. Do not use a jitterbug or vibrating screed with concrete slump exceeding 3 inches (75mm). Vibrating screeds should be moved rapidly to ensure consolidation but avoid working up an excessive layer of mortar on the surface.

HOW to Finish Concrete?

1. **LEVEL** the concrete further using a bull float, darby, or highway straightedge as soon as it has been struck-off. This operation should be completed before bleed water appears on the surface. The bull float or darby embeds large aggregate, smoothes the surface, and takes out high and low spots. Keep the bull float as flat as possible to avoid premature sealing of the surface.
2. **WAIT** for the concrete to stop "bleeding". **All** other finishing operations **must wait** until the concrete has stopped bleeding and the water sheen has left the surface. Any finishing operations done while the concrete is still bleeding **will result** in later problems, such as dusting, scaling, crazing, delamination and blisters. The waiting period depends on the setting and bleeding characteristics of the concrete and the ambient conditions. During the waiting period, protect against evaporation from the concrete surface if conditions are hot, dry and windy. Cover a small test portion of the slab to evaluate if the concrete is still bleeding. General guidance regarding whether the concrete has sufficiently set for final finishing operations is when a footprint indentation of a person standing on the slab is between 1/8 to ¼ inch (3 to 6 mm).
3. **EDGE** the concrete when required. Spade the concrete to break any bond with the form with a small mason's trowel. Use the edging tool to obtain durable rounded edges.
4. **JOINT** the concrete when required. The jointing tool should have a blade one-fourth the depth of the slab. Use a straight piece of lumber as a guide. A shallow-bit groover should only be used for decorative grooves. When saw-cutting is required, it should be done as soon as the concrete is hard enough not to be torn by the blade. Early entry saw cutting can be done before the concrete has completely hardened. See CIP 6 for jointing practices and spacing.
5. **FLOAT** the concrete by hand or machine in order to embed the larger aggregates. Floating also levels and prepares the surface for further finishing. Never float the concrete while there is still bleed water on the surface.
6. **TROWEL** the concrete when required for its end use. For sidewalks, patios , driveways and other exterior applications, troweling is not usually required. Air entrained concrete should not be troweled. If trowel finishing of air-entrained concrete is required by specifications, extreme caution should be exercised when timing the finishing operation. For a smooth floor make successive passes with a smaller steel trowel and increased pressure. Repeated passes with a steel trowel will produce a smooth floor that will be slippery when wet. Excessive troweling may create dark "trowel burns." Improperly tilting the trowel will cause an undesirable "chatter" texture.
7. **TEXTURE** the concrete surface as required after floating or troweling. For exterior concrete flatwork (sidewalks, patios or driveways) texture the concrete surface after the floating operation with a coarse or fine push-broom to give a non-slip surface. For interior flatwork texture the concrete surface after final troweling. Concrete can be finished with several decorative treatments, such as exposed aggregate, dry shake color, integral color, and stamped or patterned concrete. Decorative finishes need much more care and experience.
8. **NEVER** sprinkle water or cement on concrete while finishing it. This may cause dusting or scaling.
9. **CURE** the concrete as soon as all finishing is completed to provide proper conditions for cement hydration, which provides the required strength and durability to the concrete surface. In severe conditions slab protection may be needed even before finishing is complete. See CIP 11 for more information on curing concrete.
10. **AVOID** concrete burns to skin by following proper safety practices.

References

1. *Concrete in Practice (CIP) Series*, National Ready Mixed Concrete Association, Silver Spring, Maryland. *www.nrmca.org*
2. *Guide for Concrete Floor and Slab Construction,* ACI 302.1R, American Concrete Institute, Farmington Hills, MI. *www.concrete.org.*
3. *Slabs on Grade, ACI Concrete Craftsman Series, CCS-1*, American Concrete Institute, Farmington Hills, MI.
4. *Cement Mason's Guide*, PA122, Portland Cement Association, Skokie, IL. *www.cement.org.*
5. *Residential Concrete*, National Association of Home Builders, Washington, D.C.
6. *Sealing Effects of Finishing Tools*, Bruce Suprenant, Concrete Construction, September 1999. *www.concreteconstruction.net*.
7. *Finishing Tool Primer*, Kim Basham, Concrete Construction, July 2000.

Follow These Rules to Finish Concrete

1. Place and move concrete to its final location using procedures that avoid segregation.
2. Strike off and obtain an initial level surface without sealing the surface.
3. Wait until the bleed water disappears from the surface before starting finishing operations.
4. Use the appropriate surface texture as required for the application.
5. Avoid steel troweling air-entrained concrete.
6. Cure the concrete to ensure it achieves the desired strength and durability.

1986, 1990, 2001

Concrete in Practice

What, why & how?

NRMCA

CIP 15 - Chemical Admixtures for Concrete

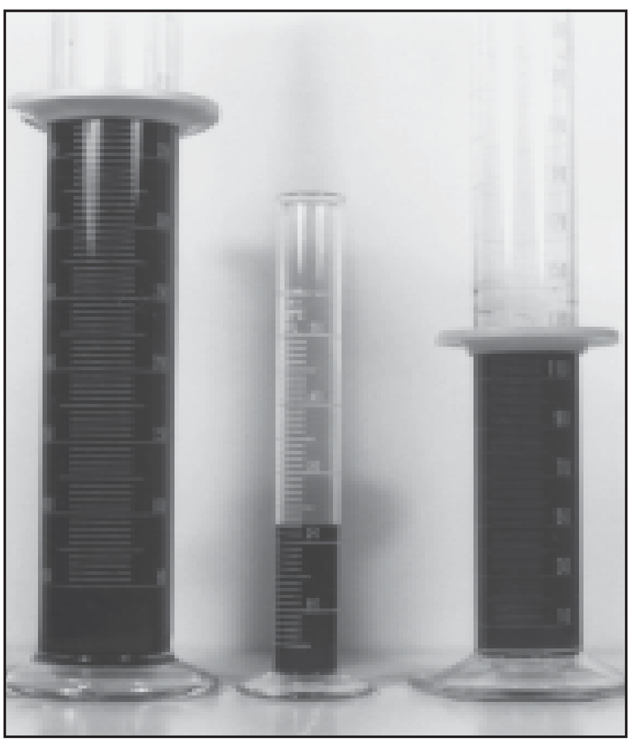
WHAT are Admixtures?

Admixtures are natural or manufactured chemicals which are added to the concrete before or during mixing. The most often used admixtures are air-entraining agents, water reducers, water-reducing retarders and accelerators.

WHY Use Admixtures?

Admixtures are used to give special properties to fresh or hardened concrete. Admixtures may enhance the durability, workability or strength characteristics of a given concrete mixture. Admixtures are used to overcome difficult construction situations, such as hot or cold weather placements, pumping requirements, early strength requirements, or very low water-cement ratio specifications.

Chemical Admixtures for Concrete



L to R: HRWR, Air-Entraining Agent, Retarder Relative quantities for one cu.yd.

HOW to Use Admixtures?

Consult your ready mixed concrete supplier about which admixture(s) may be appropriate for your application. Admixtures are evaluated for compatibility with cementitious materials, construction practices, job specifications and economic benefits before being used.

Follow This Guide to Use Admixtures

1. **AIR-ENTRAINING ADMIXTURES** are liquid chemicals added during batching concrete to produce microscopic air bubbles, called entrained air, when concrete is mixed. These air bubbles improve the concrete's resistance to damage caused by freezing and thawing and deicing salt application. In plastic concrete entrained air improves workability and may reduce bleeding and segregation of concrete mixtures. For exterior flatwork (parking lots, driveways, sidewalks, pool decks, patios) that is subject to freezing and thawing weather cycles, or in areas where deicer salts are used, specify a normal air content of 4% to 7% of the concrete volume depending on the size of coarse aggregate (see Table on next page). Air entrainment is not necessary for interior structural concrete since it is not subject to freezing and thawing. It should be avoided for concrete flatwork that will have a smooth troweled finish. In high cement content concretes, entrained air will reduce strength by about 5% for each 1% of air added; but in low cement content concretes, adding air has less effect and may even cause a modest increased strength due to the reduced water demand for required slump. Air entraining admixtures for use in concrete should meet the requirements of ASTM C 260, *Specification for Air-Entraining Admixtures for Concrete*.

2. **WATER REDUCERS** are used for two different purposes: (1) to lower the water content in plastic concrete and increase its strength; (2) to obtain higher slump without adding water. Water-reducers will generally reduce the required water content of a concrete mixture for a given slump. These admixtures disperse the cement particles in concrete and make more efficient use of cement. This increases strength or allows the cement content to be reduced while maintaining the same strength. Water-reduc-

ers are used to increase slump of concrete without adding water and are useful for pumping concrete and in hot weather to offset the increased water demand. Some water-reducers may aggravate the rate of slump loss with time. Water-reducers should meet the reuirements for Type A in ASTM C 494 *Specification for Chemical Admixtures for Concrete*.

Mid-range water reducers are now commonly used and they have a greater ability to reduce the water content. These admixtures are popular as they improve the finishability of concrete flatwork. Mid-range water reducers must at least meet the requirements for Type A in ASTM C 494 as they do not have a separate classification in an admixture specification.

3. **RETARDERS** are chemicals that delay the initial setting of concrete by an hour or more. Retarders are often used in hot weather to counter the rapid setting caused by high temperatures. For large jobs, or in hot weather, specify concrete with retarder to allow more time for placing and finishing. Most retarders also function as water reducers. Retarders should meet the requirements for Type B or D in ASTM C 494.

4. **ACCELERATORS** reduce the initial set time of concrete and give higher early strength. Accelerators do not act as an antifreeze; rather, they speed up the setting and rate of strength gain, thereby making the concrete stronger to resist damage from freezing in cold weather. Accelerators are also used in fast track construction requiring early form removal, opening to traffic or load application on structures. Liquid accelerators meeting requirements for ASTM C 494 Types C and E are added to the concrete at the batch plant. There are two kinds of accelerating admixtures: chloride based and non-chloride based. One of the more effective and economical accelerators is calcium chloride, which is available in liquid or flake form and must meet the requirements of ASTM D 98. For non-reinforced concrete, calcium chloride can be used to a limit of 2% by the weight of the cement. Because of concerns with corrosion of reinforcing steel induced by chloride, lower limits on chlorides apply to reinforced concrete. Prestressed concrete and concrete with embedded aluminum or galvanized metal should not contain any chloride-based materials because of the increased potential for corrosion of the embedded metal. Non-chloride based accelerators are used where there is concern of corrosion of embedded metals or reinforcement in concrete.

5. **HIGH RANGE WATER-REDUCERS** *(***HRWR***)* is a special class of water-reducer. Often called superplasticizers, HRWRs reduce the water content of a given concrete mixture between 12 and 25%. HRWRs are therefore used to increase strength and reduce permeability of concrete by reducing the water content in the mixture; or greatly increase the slump to produce "flowing" concrete without adding water. These admixtures are essential for high strength and high performance concrete mixtures that contain higher contents of cementitious materials and mixtures containing silica fume. For example, adding a normal dosage of HRWR to a concrete with a slump of 3 to 4 inches (75 to 100 mm) will produce a concrete with a slump of about 8 inches (200 mm). Some HRWRs may cause a higher rate of slump loss with time and concrete may revert to its original slump in 30 to 45 minutes. In some cases, HRWRs may be aded at the jobsite in a controlled manner. HRWRs are covered by ASTM Specification C 494. Types F and G, and Types 1 and 2 in ASTM C 1017 *Specification for Chemical Admixtures for Use in Producing Flowing Concrete*.

Recommended Air Content in Concrete[4]

Nominal max aggregate size, mm (in.)	Air Content, percent	
	Severe exposure	Moderate exposure
9.5 (3/8)	7.5	6
12.5 (1/2)	7	5.5
19.0 (3/4)	6	5
25.0 (1)	6	4.5
37.5 (1 1/2)	5.5	4.5
50 (2)	5	4
75 (3)	4.5	3.5

Severe exposure - concrete in cold climate will be continuously in contact with water prior to freezing or where deicing salts are used.

Moderate exposure - concrete in a cold climate will be only occasionally exposed to moisture prior to freezing and not exposed to deicing salt application.

Besides these standard types of admixtures, there are products available for enhancing concrete properties for a wide variety of applications. Some of these products include: Corrosion inhibitors, shrinkage reducing admixtures, anti-washout admixtures, hydration stabilizing or extended set retarding admixtures, admixtures to reduce potential for alkali aggregate reactivity, pumping aids, damp-proofing admixtures and a variety of colors and products that enhance the aesthetics of concrete. Contact your local ready mixed concrete producer for more information on specialty admixture products and the benefits they provide to concrete properties.

References

1. ASTM C 260, C 494, C 1017, D 98, American Society for Testing and Materials (ASTM), West Conshohocken, PA, *www.astm.org*.
2. *Chemical and Air-Entraining Admixtures for Concrete*, ACI Educational Bulletin, E4, American Concrete Institute, Farmington Hills, MI, *www.concrete.org*.
3. *Chemical Admixtures for Concrete*, ACI 212.3R, American Concrete Institute, Farmington Hills, MI.
4. *Building Code Requirements for Structural Concrete*, ACI 318, American Concrete Institute, Farmington Hills, MI.
5. *Understanding Chloride Percentages*, NRMCA Publication No. 173, NRMCA, Silver Spring, MD, *www.nrmca.org*.

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Concrete in Practice
What, why & how?
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CIP 16 - Flexural Strength Concrete

WHAT is Flexural Strength?

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. It is measured by loading 6 x 6-inch (150 x 150-mm) concrete beams with a span length at least three times the depth. The flexural strength is expressed as *Modulus of Rupture* (MR) in psi (MPa) and is determined by standard test methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading).

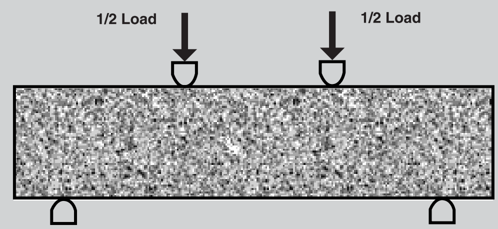
Flexural MR is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used. However, the best correlation for specific materials is obtained by laboratory tests for given materials and mix design. The MR determined by third-point loading is lower than the MR determined by center-point loading, sometimes by as much as 15%.

WHY Test Flexural Strength?

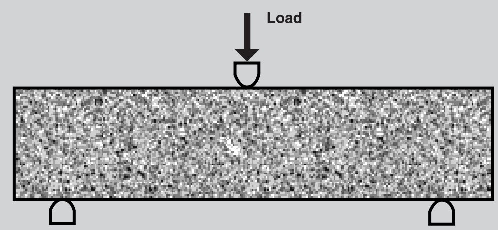
Designers of pavements use a theory based on flexural strength. Therefore, laboratory mix design based on flexural strength tests may be required, or a cementitious material content may be selected from past experience to obtain the needed design MR. Some also use MR for field control and acceptance of pavements. Very few use flexural testing for structural concrete. Agencies not using flexural strength for field control generally find the use of compressive strength convenient and reliable to judge the quality of the concrete as delivered.

How to UseFlexural Strength?

Beam specimens must be properly made in the field. Pavement concrete mixtures are stiff (1/2 to $2^{1}/_{2}$-inch slump). Consolidate by vibration in accordance with ASTM C 31 and tap sides to release air pockets. For higher slump, after rodding, tap the molds to release air pockets and spade along the sides to



ASTM C 78 - Third-Point Loading - half the load is applied at each third of the span length. MR is lower than center-point loading. Maximum stress is present over the center 1/3 portion of the beam.



ASTM C 293 - Center-Point Loading - the entire load is applied at the center span. The MR will be greater than third-point loading. The maximum stress is present only at the center of the beam.

consolidate. *Never allow the beam surfaces to dry at any time*. Immerse in saturated limewater for at least 20 hours before testing.

Specifications and investigation of apparent low strengths should take into account the higher variability of flexural strength results. Standard deviation for concrete flexural strengths up to 800 psi (5.5 MPa) for projects with good control range from about 40 to 80 psi (0.3 to 0.6 MPa). Standard deviation values over 100 psi (0.7 MPa) may indicate testing problems. There is a high likelihood that testing problems, or moisture differences within a beam caused from premature drying, will cause low strength.

Where a correlation between flexural and compressive strength has been established in the laboratory, core strengths by ASTM C 42 can be used for compressive strength to check against the desired value using the ACI 318 criteria of 85 percent of specified strength for the average of three cores. It is impractical to saw beams from a slab for flexural testing. Sawing beams will greatly reduce measured flexural strength and should not be done. In some instances, splitting tensile strength of cores by ASTM C 496 is used, but experience is limited on how to apply the data.

Another procedure for in-place strength investigation uses compressive strength of cores calibrated by comparison with acceptable placements in proximity to the concrete in question:

Method to Troubleshoot Flexural Strength Using Compressive Strength of Cores

	Lot 1	Lot 2	Lot 3
MR, psi	730 (OK)	688(?)	731 (OK)
Core, psi	4492	4681	4370

Estimate Flexural Strength of Lot 2 =

$$4681 \times \frac{730 + 731}{4492 + 4370} = 771 \text{ psi}$$

WHAT are the Problems with Flexure?

Flexural tests are extremely sensitive to specimen preparation, handling, and curing procedure. Beams are very heavy and can be damaged when handled and transported from the jobsite to the lab. Allowing a beam to dry will yield lower strengths. Beams must be cured in a standard manner, and tested while wet. Meeting all these requirements on a jobsite is extremely difficult often resulting in unreliable and generally low MR values. *A short period of drying can produce a sharp drop in flexural strength*.

Many state highway agencies have used flexural strength but are now changing to compressive strength or maturity concepts for job control and quality assurance of concrete paving. Cylinder compressive strengths are also

> *The data point to a need for a review of current testing procedures. They suggest also that, while the flexural strength test is a useful tool in research and in laboratory evaluation of concrete ingredients and proportions, it is too sensitive to testing variations to be usable as a basis for the acceptance or rejection of concrete in the field*. (Reference 3)

NRMCA and the American Concrete Pavement Association (ACPA) have a policy that compressive strength testing is the preferred method of concrete acceptance and that certified technicians should conduct the testing. ACI Committees 325 and 330 on concrete pavement construction and design and the Portland Cement Association (PCA) point to the use of compressive strength tests as more convenient and reliable.

The concrete industry and inspection and testing agencies are much more familiar with traditional cylinder compression tests for control and acceptance of concrete. Flexure can be used for design purposes, but the corresponding compressive strength should be used to order and accept the concrete. Any time trial batches are made; both flexural and compressive tests should be made so that a correlation can be developed for field control.

References:

1. *How Should Strength be Measured for Concrete Paving?* Richard C. Meininger, NRMCA TIL 420, and Data Summary, NRMCA TIL 451, NRMCA, Silver Spring, MD.
2. *Concrete Strength Testing*, Peggy Carrasquillo, Chapter 14, ASTM STP 169C, Significance of Tests and Properties of Concrete and Concrete-Making Materials, American Society for Testing and Mater-ials, West Conshohocken, PA.
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4. *Variation of Laboratory Concrete Flexural Strength Tests*, W. Charles Greer, Jr., ASTM Cement, Concrete and Aggregates, Winter, 1983, American Society for Testing and Materials, West Conshohocken, PA.
5. "Concrete Mixture Evaluation and Acceptance for Air Field Pavements" Richard C. Meininger and Norm Nelson, NRMCA Publication 178, September 1991, NRMCA, Silver Spring, MD.
6. *Compression vs. Flexural Strength for Quality Control of Pavements,* Steve Kosmatka, CTT PL 854, 1985, Portland Cement Association, Skokie, IL.
7. *Time to Rein in the Flexure Test*, Orrin Riley, ACI Concrete International, August, 1994, American Concrete Institute, Farmington Hills, MI.

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Concrete in Practice

What, why & how?

NRMCA

CIP 17 - Flowable Fill Materials

WHAT is Flowable Fill?

Flowable fill is a self-compacting low strength material with a flowable consistency that is used as an economical fill or backfill material as an alternative to compacted granular fill. Flowable fill is not concrete nor it is used to replace concrete. Terminology used by ACI Committee 229 is *Controlled Low Strength Material (CLSM)*. Other terms used for this material are unshrinkable fill, controlled density fill, flowable mortar or lean-mix backfill.

In terms of its flowability, the slump, as measured for concrete, is generally greater than 8 inches (200 mm). It is self-leveling material and can be placed with minimal effort and does not require vibration or tamping. It hardens into a strong material with minimal subsidence.

While the broader definition includes materials with compressive strength less than 1200 psi (8.3 MPa), most applications use mixtures with strength less than 300 psi (2.1 MPa). The late-age strength of removable CLSM materials should be in the range of 30 to 200 psi (0.2 to 1.4 MPa) as measured by compressive strength of cylinders. It is important that the expectation of future excavation of flowable fill material be stated when specifying or ordering the material.

WHY is Flowable Fill Used?

Flowable fill is an economical alternative to compacted granular fill considering the savings in labor costs, equipment and time. Since it does not need manual compaction, trench width or the size of excavation is significantly reduced. Placing flowable fill does not require people to enter an excavation, a significant safety concern. CLSM is also an excellent solution for filling inaccessible areas, such as underground tanks, where compacted fill cannot be placed.

Uses of Flowable Fill include:

1. Backfill - sewer trenches, utility trenches, bridge abutments, conduit encasement, pile excavations, retaining walls, and road cuts.
2. Structural Fill - foundation sub-base, subfooting, floor slab base, pavement bases, and conduit bedding.
3. Other Uses - abandoned mines, underground storage tanks, wells, abandoned tunnel shafts and sewers, basements and underground structures, voids under pavement, erosion control, and thermal insulation with high air content flowable fill.

How is Flowable Fill Ordered?

Ask for it by intended use and indicate whether excavatability in the future is required. Ready mixed concrete producers generally have developed mixture proportions for flowable fill products that make best use of economical aggregates, fly ash and other materials. Frequently site-excavated materials and materials that do not meet standards for use in concrete can be incorporated in flowable fill mixtures.

Strength - For later excavatability the ultimate strength of the flowable fill must be kept below 200 psi (1.4 MPa) to allow excavation by mechanical equipment, like backhoes. For manual excavation the ultimate strength should be less than 50 psi (0.3 MPa). Mixtures containing large amounts of coarse aggregate are more difficult to excavate. Mixtures with entrained air in excess of 20% by volume are used to keep the strength low.

Higher strength structural fills can be designed for a specific required strength. Compressive strength of 50 to 100 psi (0.3 to 0.7 MPa) provides an allowable bearing capacity similar to well-compacted soil.

Setting and Early Strength may be important where equipment, traffic, or construction loads must be carried or subsequent construction needs to be scheduled. Judge the setting characteristics by scraping off loose accumulations of water and fines on top and see how much force is necessary to cause an indentation in the material. ASTM C 403 or ASTM D 6024 may be used to estimate the load carrying ability of the flowable fill. Penetration values by C 403 between 500 and 1500 psi are adequate for loading flowable fill.

Density in place is usually in the 115 to 145 lb./cu. ft. range for non-air entrained or conventionally air-entrained mixtures. These densities are typically higher than most compacted fills. If lightweight fills are needed to reduce the weight or to provide greater thermal insulation, high entrained air (greater than 20%) mixtures, preformed foam or lightweight aggregates may be used.

Flowability of flowable fill is important, so the mixture will flow into place and consolidate due to its fluidity without vibration or puddling action. The flowability can be varied to suit the placement requirements of most applications. Hydrostatic pressure and floatation of pipes should be considered by appropriate anchorage or by placing in lifts.

Subsidence of some flowable fill mixtures with high water content is on the order of 1/4 inch per foot (20 mm per meter) of depth as the solid materials settle. Mixtures with high air content use less water and have little or no subsidence.

Permeability of flowable mixtures can be varied significantly to suit the application. Most mixtures have permeability similar to or lower than compacted soil.

Durability - Flowable fill materials are not designed to resist freezing and thawing, abrasive or most erosive actions, or aggressive chemicals. If these properties are required, use a high quality concrete. Fill materials are usually buried in the ground or otherwise confined. If flowable fill deteriorates in place it will continue to act as a granular fill.

How is Flowable Fill Delivered and Placed?

Flowable fill is delivered by ready mixed concrete truck mixers and placed easily by chute in a flowable condition directly into the cavity to be filled. To avoid segregation, the drum should be kept agitating. Flowable fill can be conveyed by pump, chutes or buckets to its final location. For efficient pumping, some granular material is needed in the mixture. Due to its fluid consistency it can flow long distances from the point of placement.

Flowable fill does not need to be cured like concrete but should be protected from freezing until it has hardened.

References:

1. *Controlled Low Strength Materials*, ACI 229R, American Concrete Institute, Farmington Hills, MI.
2. *Recommended Guide Specification for CLSM (Flowable Fill)*, NRMCA Publication 2PFFGS, National Ready Mixed Concrete Association, Silver Spring, MD.
3. ASTM *Book of Standards, Volumes 04.09 and 04.02*, American Society for Testing and Materials, West Conshohocken, PA.
4. *Controlled Low Strength Materials*, ACI SP-150, ed. W.S. Adaska, American Concrete Institute, Farmington Hills, MI.
5. *The Design and Application of Controlled Low-Strength Materials (Flowable Fill)*, ASTM STP 1331, ed. A.K. Howard and J.L. Hitch, American Society for Testing and Materials, West Conshohocken, PA.
6. *Controlled Low-Strength Materials*, W.S. Adaska, Concrete International, April 1997, pp. 41-43, American Concrete Institute, Farmington Hills, MI.

Testing Flowable Fill Mixtures

Quality assurance testing is not necessary for pre-tested standard mixtures of flowable fill. Visual checks of mixture consistency and performance have proven adequate. Test methods and acceptance criteria for concrete are generally not applicable. Testing may be appropriate with new mixtures or if non-standard materials are used.

- Obtain samples for testing flowable fill mixtures in accordance with ASTM D 5971.
- Flow consistency is measured in accordance with ASTM D 6103. A uniform spread diameter of at least 8 in. without segregation is necessary for good flowability. Another method of measuring flowability is with a flow cone, ASTM C 939. The mixture tested should not contain coarse aggregate retained on the No. 4 (4.75-mm) sieve. An efflux time of 10 to 26 sec is generally recommended.
- Unit weight, yield and air content of flowable fill are measured by ASTM D 6023.
- Preparing and testing cylinders for compressive strength is described in ASTM D 4832. Use 3 x 6 in. (75 x 150 mm) plastic cylinder molds, fill to overflowing and then tap sides lightly. Other sizes and types of molds may be used as long as the length to diameter ratio is 2 to 1. Cure cylinders in the molds (covered) until time of testing (or at least 14 days). Strip carefully using a knife to cut plastic mold off. Capping with sulfur compounds can damage these low strength specimens. Neoprene caps have been used but high strength gypsum plasters seem to work best.
- Penetration resistance tests such as ASTM C 403 may be useful in judging the setting and strength development. Penetration resistance numbers of 500 to 1500 indicate adequate hardening. A penetration value of 4000, which is roughly 100 psi (0.7 MPa) compressive cylinder strength, is greater than the bearing capacity of most compacted soil. Another method of testing for adequate hardening after placement is the ball drop test, ASTM D 6024. A diameter of indentation of less than 3 in. (75 mm) is considered adequate for most load applications. A relationship between the strength gain of the flowable fill and the penetration resistance can be developed for specific mixtures.

CAUTIONS

1. Flowable fill while fluid is a heavy material and during placement will exert a high fluid pressure against any forms, embankment, or walls used to contain the fill.
2. Placement of flowable fill around and under tanks, pipes, or large containers, such as swimming pools, can cause the container to float or shift.
3. In-place fluid flowable fill should be covered or cordoned off for safety reasons.

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CIP 18 - Radon Resistant Buildings

WHAT is Radon?

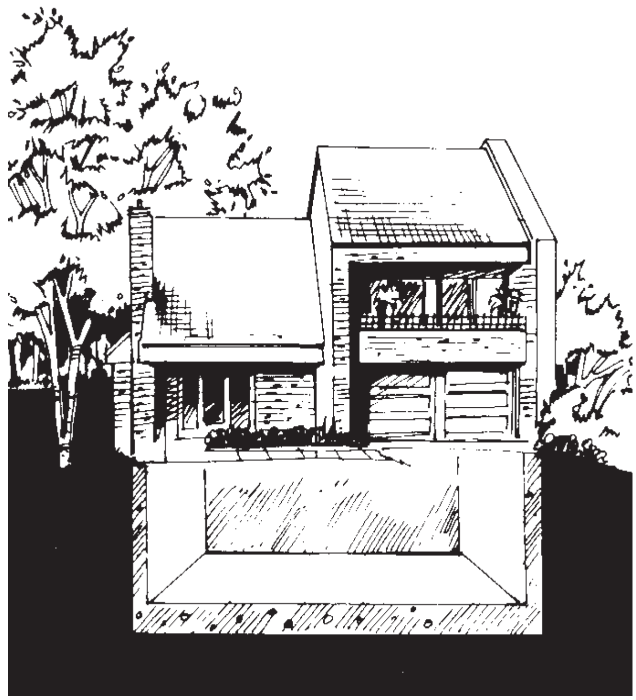
Radon is a colorless, odorless, radioactive gas which occurs naturally in soils in amounts dependent upon the geology of the location. The rate of movement of radon through the soil is dependent primarily upon soil permeability and degree of saturation, and differences in air pressure within the soil. Soil gas enters buildings through cracks or openings in the foundation, slab, or basement walls when the air pressure in the building is less than that of the soil.

Radon gas decays to other radioactive elements in the uranium series. Called "radon progeny," they exist as solid particles rather than as a gas.

WHY be Concerned About Radon Levels in Buildings?

The concern is due to an association with the development of lung cancer. Radon progeny can become attached to dust particles in the air. If inhaled, they can lodge in the lung. Energy emitted during radioactive decay while in the lung can cause tissue damage, which has been linked to lung cancer.

The level of health risk associated with radon is related to the concentration of radon in the air and the time a person is exposed to that air. The U.S. Environmental Protection Agency (EPA) has developed a risk profile for radon exposure at various concentrations, and established an action level concentration above which efforts should be made to reduce radon levels.[1] It is prudent to take measures during construction which will reduce the amount of radon entering a building.



Eliminate Entry Routes for Soil Gases by Proper Jointing, Sealing, and (When Necessary) Venting.

HOW to Construct Radon Resistant Concrete Buildings?

Solid concrete is an excellent material for use in constructing radon resistant buildings. It is an effective barrier to soil gas penetration if cracks and openings are sealed.

Solid concrete slabs and basement walls are commonly used in residential buildings. Buildings resistant to radon may be easily constructed with concrete. In concrete construction, the critical factor is to eliminate all entry routes through which gases can flow from the soil into the building.

The construction of radon resistant buildings requires adhering to accepted construction practices with attention to a few additional details. In instances where high radon levels are expected, installation of a sub-slab ventilation system incorporating an open-graded aggregate base beneath the slab may be warranted during construction. These systems provide a positive means of evacuating soil gas from beneath the slab, diverting it directly to the outside.[2,3]

References

1. "A Citizen's Guide to Radon—What It Is and What To Do About It," U.S. Environmental Protection Agency, OPA-86-004, 1986, 13 pp. Available from state radiation protection offices or EPA regional offices.

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4. "Production of Radon-Resistant Slab on Grade Foundations," Florida Institute of Phosphate Research, Bartown, Florida, 1987, 9 pp.

5. "Guide to Residential Cast-In-Place Concrete Construction," ACI 332R, American Concrete Institute, Farmington Hills, MI.

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7. Technical information on radon-resistant construction is available from the National Association of Home Builders, National Research Center, Radon Research Program, (301) 249-4000.

Follow these Guidelines to Reduce Radon Entry:

1. Design to minimize utility openings. Sump openings should be sealed and vented outdoors.[2]
2. Minimize random cracking by using control and isolation joints in walls and floors. Planned joints can then be easily sealed.[5] If done properly, any cracks will occur at the joints and can be easily sealed.
3. Monolithic slab foundations are an effective way to minimize radon entry.[2,4,6] For slab on grade homes in warm climates, pour foundation and slab as a single monolithic unit.
4. Use materials which will minimize concrete shrinkage and cracking (larger aggregate sizes and proper water-cementitious ratio).
5. When using polyethylene film beneath the slab, place a layer of sand over the polyethylene. See CIP 5 and 7.
6. Remove grade stakes after striking off the slab. (If left, they can provide entryways through the slab.)[2]
7. Construct the joints to facilitate caulking.[5]
8. Cure the concrete adequately. See CIP 11.
9. Caulk and seal all joints and openings in the walls or floor. (If cracks occur, they should be widened, and then caulked and sealed.)[2,3]

1982, 1989 AND 2000

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CIP 19 - Curling of Concrete Slabs

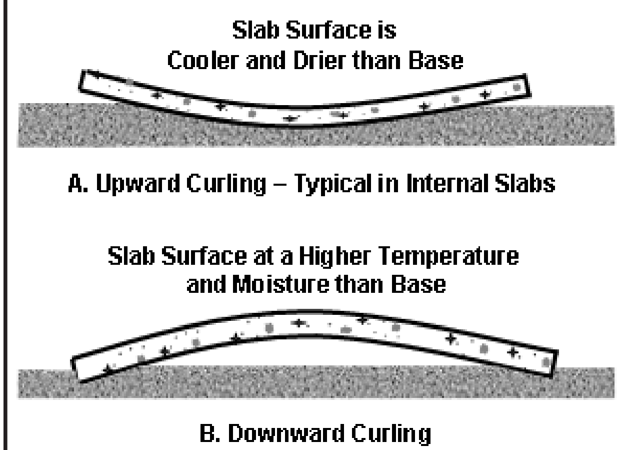
WHAT is Curling?

Curling is the distortion of a slab into a curved shape by upward or downward bending of the edges. The occurrence is primarily due to differences in moisture and/or temperature between the top and bottom surfaces of a concrete slab. The distortion can lift the edges or the middle of the slab from the base, leaving an unsupported portion. The slab section can crack when loads exceeding its capacity are applied. Slab edges might chip off or spall due to traffic when the slab section curls upwards at its edges. In most cases, curling is evident at an early age. Slabs may, however, curl over an extended period.

WHY do Concrete Slabs Curl?

Changes in slab dimensions that lead to curling are most often related to moisture and temperature gradients in the slab. When one surface of the slab changes size relative to the other, the slab will warp at its edges in the direction of relative shortening. This curling is most noticeable at the sides and corners. One primary characteristic of concrete that affects curling is drying shrinkage. Anything that increases drying shrinkage of concrete will tend to increase curling.

The most common occurrence of curling is when the top surface of the slab dries and shrinks with respect to the bottom. This causes an upward curling of the edges of a slab (Figure 1A). Curling of a slab soon after placement is most likely related to poor curing and rapid surface drying. In slabs, excessive bleeding due to high water content in the concrete or water sprayed on the surface; or a lack of surface moisture due to poor or inadequate curing can create increased surface drying shrinkage relative to the bottom of the slab. Bleeding is accentuated in slabs placed directly on a vapor retarder (polyethylene sheeting) or when topping mixtures are placed on concrete slabs. Shrinkage differences from top to bottom in these cases are larger than for slabs on an absorptive subgrade.



Curling of Concrete Slabs

Thin slabs and long joint spacing tend to increase curling. For this reason, thin unbonded toppings need to have a fairly close joint spacing.

In industrial floors, close joint spacing may be undesirable because of the increased number of joints and increased joint maintenance problems. However, this must be balanced against the probability of intermediate random cracks and increased curling at the joints.

The other factor that can cause curling is temperature differences between the top and bottom of the slab. The top part of the slab exposed to the sun will expand relative to the cooler bottom causing a downward curling of the edges (Figure 1B). Alternately, during a cold night when the top surface cools and contracts relative to the bottom surface in contact with a warmer subgrade, the curling due to this temperature differential will add to the upward curling caused by moisture differentials.

HOW to Minimize Slab Curling?

The primary factors controlling dimensional changes of concrete that lead to curling are drying shrinkage, construction practices, moist or wet subgrades, and day-night temperature cycles. The following practices will help to minimize the potential for curling:

1. Use the lowest practical water content in the concrete.
2. Use the largest practical maximum size aggregate and/or the highest practical coarse aggregate content to minimize drying shrinkage.
3. Take precautions to avoid excessive bleeding. In dry conditions place concrete on a damp, but absorptive, subgrade so that all the bleed water is not forced to the top of the slab. This may not be appropiate for interior slabs on which a moisture sensitive floor covering would be placed.
4. Avoid using polyethylene vapor retarders unless covered with at least four inches (100 mm) of a trimable, compactible granular fill (not sand). If a moisture-sensitive floor covering will be placed on interior slabs, the concrete will generally be placed directly on a vapor retarder (see CIP29) and other procedures may be necessary.
5. Avoid a higher than necessary cement content. Use of pozzolan or slag is preferable to very high cement content.
6. Cure the concrete thoroughly, including joints and edges. If membrane-curing compounds are used, apply at twice the recommended rate in two applications at right angles to each other.
7. When minimizing curling is critical, use a joint spacing not exceeding 24 times the thickness of the slab.
8. For thin toppings, clean the base slab to ensure bond and consider use of studs and wire around the edges and particularly in the slab corners.
9. Use a thicker slab, or increase the thickness of the slab at edges.
10. The use of properly designed and placed slab reinforcement may help reduce or eliminate curling. Load transfer devices that minimize vertical movement should be used across construction joints.
11. Certain types of breathable sealers or coatings on slabs can work to minimize moisture differentials and reduce curling.

When curling in a concrete slab application cannot be tolerated alternate options include the use of shrinkage reducing admixtures, shrinkage-compensating concrete, post tensioned slab construction or vacuum dewatering. These options should be decided before the construction and could increase the initial cost of the project.

Some methods of remedying slab curling include ponding the slab to reduce curl followed by sawing additional contraction joints, grinding slab joints where curling has occurred to restore serviceability and injecting a grout to fill voids under the slab to restore support and prevent break-off of uplifted edges.

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Concrete in Practice

What, why & how?

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CIP 20 - Delamination of Troweled Concrete Surfaces

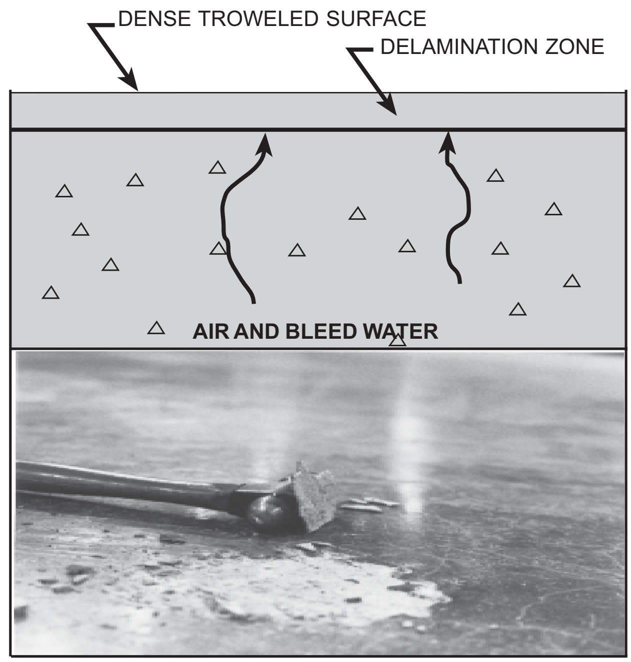
WHAT are Delaminations?

In most delaminated concrete slab surfaces, the top $^1/_8$ to ¼ inch (3 to 6 mm) is densified, primarily due to premature and improper finishing, and separated from the base slab by a thin layer of air or water. The delaminations on the surface of a slab may range in size from several square inches to many square feet. The concrete slab surface may exhibit cracking and color differences because of rapid drying of the thin surface during curing. Traffic or freezing may break away the surface in large sheets. Delaminations are similar to blisters, but much larger (see CIP 13).

Delaminations form during final troweling. They are more frequent in early spring and late fall when concrete is placed on a cool subgrade with rising daytime temperatures, but they can occur at anytime depending on the concrete characteristics and the finishing practices used.

Corrosion of reinforcing steel near the concrete surface or poor bond between two-course placements may also cause delaminations (or spalling). The resulting delaminations are generally thicker than those caused by improper finishing.

Delaminations are difficult to detect during finishing but become evident after the concrete surface has set and dried. Delaminations can be detected by a hollow sound when tapped with a hammer or with a heavy chain drag. A procedure is described in ASTM D 4580, *Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding*. More sophisticated techniques include acoustic impact echo and ground-penetrating radar.



Delaminated Concrete

WHY does Delamination Occur?

Bleeding is the upward flow of mixing water in plastic concrete as a result of the settlement of the solids. Delamination occurs when the fresh concrete surface is sealed or densified by troweling while the underlying concrete is still plastic and continues to bleed and/or to release air. Delaminations form fairly late in the finishing process after floating and after the first troweling pass. They can, however, form during the floating operation if the surface is overworked and densified. The chances for delaminations are greatly increased when conditions promote rapid drying of the surface (wind, sun, or low humidity). Drying and higher temperature at the slab surface makes it appear ready to trowel while the underlying concrete is plastic and can still bleed or release air. Vapor retarders placed directly under slabs force bleed water to rise and compound the problem.

Factors that delay initial set of the concrete and reduce the rate of bleeding will increase the chances for delaminations. Entrained air in concrete reduces the rate of bleeding and promotes early finishing that will produce a dense impermeable surface layer. A cool subgrade delays set in the bottom relative to the top layer.

Delamination is more likely to form if:

1. The underlying concrete sets slowly because of a cool subgrade.
2. The setting of the concrete is retarded due to concrete temperature or mixture ingredients.
3. The concrete has entrained air or the air content is higher than desirable for the application.
4. The concrete mixture is sticky from higher cementitious material or sand-fines content.
5. Environmental conditions during placement are conducive

to rapid drying causing the surface to “crust” and appear ready to finish.

6. Concrete is excessively consolidated, such as the use of a jitterbug or vibrating screed that brings too much mortar to the surface.
7. A dry shake is used, particularly with air-entrained concrete.
8. The slab is thick.
9. The slab is placed directly on a vapor retarder.

Corrosion-related delaminations are formed when the upper layer of reinforcing steel rusts thereby breaking the bond between the steel and the surrounding concrete. Corrosion of steel occurs with reduced concrete cover and when the concrete is relatively more permeable causing chlorides to penetrate to the layer of the steel (See CIP 25).

HOW to Prevent Delamination?

Accelerators or heated concrete often prevent delamination in cool weather.

Be wary of a concrete surface that appears to be ready to trowel before it would normally be expected. Emphasis in finishing should be on screeding, straight-edging, and floating the concrete as rapidly as possible—without working up an excessive layer of mortar and without sealing the surface layer. In initial floating, the float blades should be flat to avoid densifying the surface too early.

Final finishing operations to produce a smooth surface should be delayed as long as possible, and the surface covered with polyethylene or otherwise protected from evaporation.

Delamination may be difficult to detect during finishing operations. If delamination is observed, tear the surface with a wood float and delay finishing as long as possible. Any steps that can be taken to slow evaporation should help.

If a vapor retarder is required, place at least four inches (100 mm) of a trimable, compactible granular fill (not sand). Do not place concrete directly on a vapor retarder. If a moisture-sensitive floor covering will be placed on interior slabs, concrete will generally be placed directly on a vapor retarder (see CIP 29), and other procedures may be necessary.

Do not use air-entrained concrete for interior floor slabs that have a hard troweled surface and that will not be subject to freeze-thaw cycles or deicing salt application. If entrained air is necessary to protect interior slabs from freezing and thawing cycles during construction avoid using air contents over 3%.

Delaminated surfaces can be repaired by patching after the surface layer is removed and the underlaying concrete is properly cleaned. Extensive delamination may need to be repaired by grinding and overlaying a new surface. Delaminated surfaces due to steel corrosion will additionally require sandblasting to remove rust from the steel.

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Follow These Rules to Avoid Delamination

1. Do not seal surface early—before air or bleed water from below have escaped.
2. Avoid dry shakes on air-entrained concrete.
3. Use heated or accelerated concrete to promote even setting throughout slab depth.
4. Avoid placing concrete directly on vapor retarders, if the application allows.
5. Do not use air-entrained concrete for interior slabs that will receive a trowel finish.
6. Avoid placing concrete on substrate with a temperature of less than 40° F (4° C).

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CIP 21 - Loss of Air Content in Pumped Concrete

WHAT is Air Loss in Pumping?

Increasingly, specifiers are testing concrete at the discharge end of concrete pumps and, in some cases, finding air contents much lower than that in samples tested at the truck chute. It is normal to find 0.5 to 1.0 percent less air at the pump discharge. However, when the new 5" line, long boom pumps have the boom in an orientation with a long, near vertical downward section of pipe, the air content at discharge may be less than half of that of the concrete going into the pump hopper. When the boom is upward or horizontal, except for a 12 ft. section of rubber hose, there generally is no significant loss of air. There is some controversy over how frequently air loss is a problem in pumped concrete. Certainly, it doesn't occur every time, or even most times. However, it does occur often enough to be considered seriously until better solutions are developed.

WHAT is Air Loss?

There are several mechanisms involved, but air loss will occur if the weight of concrete in a vertical or near vertical downward pipe is sufficient to overcome frictional resistance and let a slug of concrete slide down the pipe. One part of the theory is that when the concrete slides down the pipe, it develops a vacuum which greatly expands the air bubbles; and when they hit an elbow in the boom or a horizontal surface, the bubbles collapse. You can demonstrate the effect of the impact by dropping concrete 15 or 20 ft. into a tray. Naturally, the transition from several hundred psi of pressure in the line to a near vacuum condition may make matters worse. Most field experience suggests that air loss is greatest with high cement content, flowable concrete mixes which slide down easier; however, air loss has also been experienced with $5\frac{1}{2}$ sack concrete of moderate slump.

HOW to Prevent Loss?

Keep concrete from sliding down the line under its own weight. Where possible, avoid vertical or steep downward boom sections. Be cautious with high slumps, particularly with high cement content mixes and mixes containing silica fume. Steady, moderately rapid pumping may help somewhat to minimize air loss, but will not solve most problems.

a) Try inserting four 90 degree elbows just before the rubber hose. *(Do not* do this unless pipe clamps are designed to comply with *all safety requirements.)* This helps, but won't be a perfect solution.

b) Use a slide gate at the end of the rubber hose to restrict discharge and provide resistance.

c) Use of a 6 ft. diameter loop in the rubber hose with an extra section of rubber hose is reported to be a better solution than (a) or (b).

d) Lay 10 or 20 ft. of hose horizontally on deck pours. This doesn't work in columns or walls and requires labor to handle the extra hose.

e) Reduce the rubber hose size from 5 to 4 in. A transition pipe may be needed to avoid blockages.

PRECAUTIONS

a) Before the pour, plan alternative pump locations and decide what will be done if air loss occurs. Be prepared to test for air content frequently.

b) Sampling from the end of a pump line can be very difficult. Wear proper personal protective equipment. Never sample the initial concrete through the pump line.

c) Sample the first load on the job after pumping 3 or 4 cu. yds. Temper it to the maximum permissible slump. Swing the boom over near the pump to get the maximum length of vertical downward pipe and drop the sample in a wheel barrow. If air is lost, take precautions and sample at the point of placement.

d) If air loss occurs, do not try to solve the problem by increasing the air content delivered to the pump beyond the upper specification limit. High air content concrete with low strength could, or almost surely will, be placed in the structure if boom angles are reduced or somewhat lower slump concrete is pumped.

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Concrete in Practice

What, why & how?

NRMCA

CIP 22 - Grout

WHAT is Grout?

ACI[1] defines grout as "a mixture of cementitious material and water, with or without aggregate, proportioned to produce a pourable consistency without segregation of the constituents."

The terms grout and mortar are frequently used interchangeably but there are clear distinctions. *Grout* need not contain aggregate whereas *mortar* contains fine aggregate. *Grout* is supplied in a pourable consistency whereas *mortar* is not. *Grout* fills space whereas *mortar* bonds elements together, as in masonry construction.

Grout is often identified by its application. Some examples are: bonded prestressed tendon grout, auger cast pile grout, masonry grout, and pre-placed aggregate grout. Controlled low strength material (flowable fill) is a type of grout.

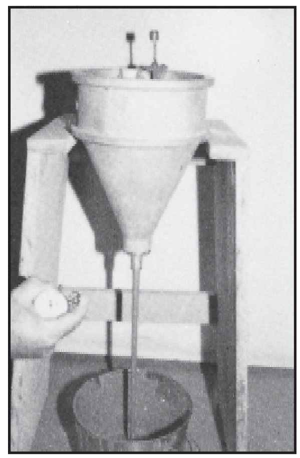
WHY does Delamination Occur?

Grout is used to fill space or cavities and provide continuity between building elements. In some applications, grout will act in a structural capacity. In projects where small quantities of grout are required, it is proportioned and mixed on site. The ready mixed concrete producer is generally called upon when large quantities are needed.

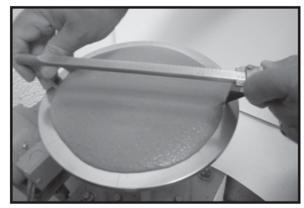
HOW to Specify Grout?

ASTM C 476 for masonry grout dictates proportions by loose volumes and is convenient for small quantities of grout mixed on site. These grout mixtures have high cement contents and tend to produce much higher strengths[4] than specified in ACI 530[5] or Model Codes.

When grout is ordered from a ready mixed concrete producer, the specifications should be based on consistency and compressive strength. Converting loose volume proportions into batch weights per cubic yard is subject to errors and can lead to controversies on the job.



Flow Cone



Flow Table

Specifications should address the addition of any required admixtures for grout. Conditions of delivery, such as temperature, time limits, and policies on job site addition of water, should be specified. Testing frequency and methods of acceptance must be covered in specifications.

HOW to Test Grout?

The consistency of grout affects its strength and other properties. It is critical that grout consistency permit the complete filling of void space without segregation of ingredients.

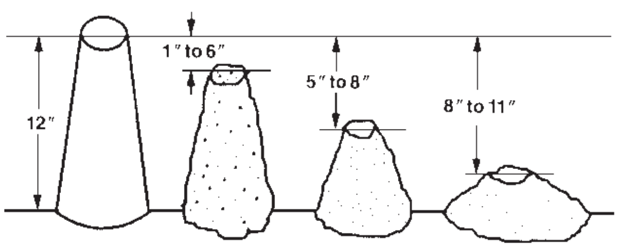
Consistency of masonry grout may be measured with a slump cone (ASTM C 143), and slumps of 8-11 in. are suggested. This is particularly applicable for grouts containing $^{1}/_{2}$ in. or smaller coarse aggregate.

For grouts without aggregate, or only fine aggregate passing a No. 8 sieve, consistency is best determined with a flow cone (ASTM C 939). For flow values exceeding 35 seconds, use the flow table in ASTM C 109, so modified to use 5 drops in 3 seconds.

Masonry grout ("blockfill") for strength tests specimens should be cast in molds formed by masonry units having the same absorption characteristics and moisture content as the units used in construction (ASTM C 1019). Never use nonabsorbent cube or cylinder molds for this purpose.

Strength of other types of grout is determined using 2 in. cubes per ASTM C 942. Method C 942 allows for field preparation, recognizes fluid consistency, and also affords a means for determining compressive strength of grouts that contain expansive agents or grout fluidifiers. This is extremely important since "expansive" grouts can lose substantial compressive strengths if cubes are not confined. However, cylindrical specimens (6 x 12 in. or 4 x 8 in.), may give more reliable results for grouts containing coarse aggregate.

Special application grouts often require modification of standard test procedures. All such modifications should be noted in the specifications and discussed prior to the start of the job.



Comparison of typical slumps

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CIP 23 - Discoloration

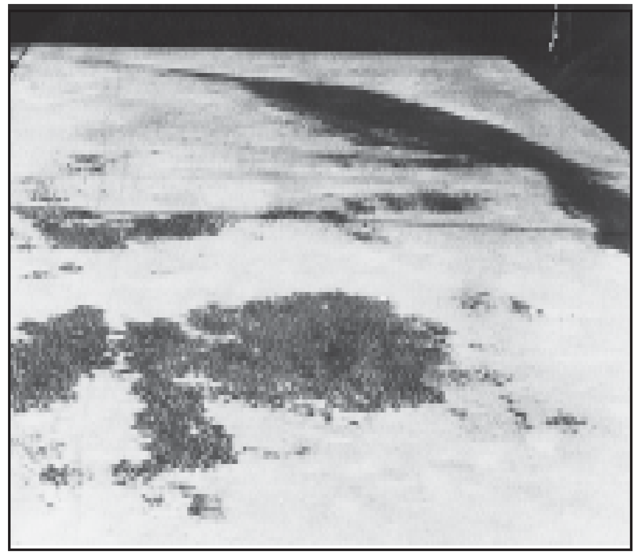
WHAT is Discoloration?

Surface discoloration is the non-uniformity of color or hue on the surface of a single concrete placement. It may take the form of dark blotches or mottled discoloration on flatwork surface, gross color changes in large areas of concrete caused by a change in the concrete mix, or light patches of discoloration caused by efflorescence. In this context, it is not intended to include stains caused by foreign material spilled on a concrete surface.[6]

WHY does Discoloration Occur?

Discoloration due to changes in cement or fine aggregate sources in subsequent batches in a placement sequence could occur, but is generally rare and insignificant. Cement that has hydrated to a greater extent will generally be lighter in color. Inconsistent use of admixtures, insufficient mixing time, and improper timing of finishing operations can cause this effect. A yellowish to greenish hue may appear on concrete containing ground slag as a cementitious material. This will disappear with time. Concrete containing ground slag does, however, have a generally lighter color. The discoloration of concrete cast in forms or in slabs on grade is usually the result of a change in either the concrete composition or a concrete construction practice. In most studies, no single factor seemed to cause discoloration.

Factors found to influence discoloration are: the use of calcium chloride, variation in cement alkali content, delayed hydration of the cement paste, admixtures, hard-troweled surfaces, inadequate or inappropriate curing, concreting practices and finishing procedures that cause surface variation of the water-cement ratio, and changes in the concrete mix.[1,2,3,7]



HOW to Prevent Discoloration?

1. Minimizing or eliminating the use of high-alkali content cements will reduce the occurrence of discoloration.

2. Calcium chloride in concrete is a primary cause of concrete discoloration. The chances for discoloration are much less if calcium chloride or chloride-bearing chemical admixtures are not used.

3. The type, kind, and condition of formwork can influence surface color. Forms with different rates of absorption will cause surfaces with different shades of color. A change in the type or brand of a form release agent can also change concrete color.

4. Eliminate trowel burning of the concrete. The most common consequence is that metal fragments from the trowel are embedded in the surface of the concrete. Also, concrete which has been hard-troweled may have dark discoloration as a result of den-

sifying the surface, which reduces the water-cement ratio. The resulting low water-cement ratio affects the hydration of the cement ferrites which contributes to a darker color. Concrete surfaces that are troweled too early will increase the water-cement ratio at the surface and lighten the color.

5. Concrete which is not properly or uniformly cured may develop discoloration. Uneven curing will affect the degree of hydration of the cement. Curing with polyethylene may also cause discoloration. When the plastic sheeting is in direct contact with the concrete, it will cause streaks. Using an even application of a quality spray or curing compound may be the better alternative.

6. The discoloration of a slab may be minimized or prevented by moistening absorptive subgrades, following proper curing procedures, and adding proper protection of the concrete from drying by the wind and sun.

HOW to Remove Discoloration?

Certain treatments have been found to be successful in removing or decreasing the surface discoloration of concrete flatwork. Discoloration caused by calcium chloride admixtures and some finishing and curing methods can be reduced by repeated washing with hot water and a scrub brush. The slab should be alternately flushed and brushed, and then dried overnight until the discoloration disappears.

If a discoloration persists, a dilute solution (1% concentration) of hydrochloric (muriatic) acid or dilute solutions (3% concentration) of weaker acids like acetic or phosphoric acid may be tried. Prior to using acids, dampen the surface to prevent it from penetrating into the concrete and flush with clean water within 15 minutes of application.

The use of a 20% to 30% water solution of diammonium citrate (2 lbs. in 1 gallon of water) has been found to be a very effective treatment by the PCA for more severe cases of discoloration.[4,5,6] Apply the solution to a dried surface for 15 minutes. A whitish gel that forms should be diluted with water and brushed. Subsequently, the gel should be completely washed off with water. More than one treatment may be required.

Some types of discoloration, such as trowel burning, may not respond to any treatment. It may be necessary to paint or use another type of coating to eliminate the discoloration. Some types of discoloration may, however, fade with wear and age.

PRECAUTIONS?

Chemical methods to remove discoloration may significantly alter the color of concrete surfaces. Inappropriate or improper use of chemicals to remove discoloration may aggravate the situation. A trial treatment on an inconspicuous area is recommended. Acids should be thoroughly flushed from a concrete surface.

CAUTIONS

The user of chemicals should refer to a Material Safety Data Sheet (MSDS) or manufacturer guidelines to be aware of the toxicity, flammability, and/or health hazards associated with the use of the material. The appropriate safety procedures, such as the use of gloves, goggles, respirators, and waterproof clothing, are recommended.

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Concrete in Practice
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CIP 24 - Synthetic Fibers for Concrete

WHAT are Synthetic Fibers?

Synthetic fibers specifically engineered for concrete are manufactured from man-made materials that can withstand the long-term alkaline environment of concrete. Synthetic fibers are added to concrete before or during the mixing operation. The use of synthetic fibers at typical addition rates does not require any mix design changes.

WHY Use Synthetic Fibers ?

Synthetic fibers benefit the concrete in both the plastic and hardened state. Some of the benefits include:

- reduced plastic settlement cracks
- reduced plastic shrinkage cracks
- lowered permeability
- increased impact and abrasion resistance
- providing shatter resistance

Some synthetic fibers may be used as secondary reinforcement. (Hardened Concrete Performance Documentation Required.)

HOW do Synthetic Fibers Work in Early Age Concrete?

Early age volume changes in concrete cause weakened planes and cracks to form because a stress exists which exceeds the strength of the concrete at a specific time. The growth of these micro shrinkage cracks is inhibited by mechanical blocking action of the synthetic fibers. The internal support system of the synthetic fibers inhibits the formation of plastic settlement cracks. The uniform distribution of fibers throughout the concrete discourages the development of large capillaries caused by bleed water migration to the surface. Synthetic fibers lower permeability through the combination of plastic crack reduction and reduced bleeding characteristics.

HOW do Synthetic Fibers Work in Hardened Concrete?

The early age concrete benefits of using synthetic fibers continue to contribute to the hardened concrete. Hardened concrete attributes provided by synthetic fibers are lowered permeability and the resistance to shattering, abrasion, and impact forces.

The ability to resist shattering forces is greatly enhanced with the introduction of synthetic fibers to the concrete. When plain concrete is compressed, it will shatter and fail at first crack. Synthetic fibers manufactured specifically for concrete prevent the effect of shattering forces by tightly holding the concrete together.

Abrasion resistance is provided when synthetic fibers are used because the water-cement ratio at the surface is not lowered by variable bleed water. The water-cement ratio is more constant at the concrete surface. This improvement is assisted by the internal settlement support value of the synthetic fibers contributing to uniform bleeding.

Synthetic fibers reduce the amount of plastic cracking of the concrete. This improves the impact resistance of concrete. The relatively low modulus of the synthetic fibers provides shock absorption characteristics.

Synthetic fibers help the concrete develop its optimum long-term integrity by the reduction of plastic settlement and shrinkage crack formation, lowered permeability, and increased resistance to abrading, shattering, and impact forces. Synthetic fibers are compatible with all admixtures, silica fumes, and cement chemistries.

HOW are Synthetic Fibers Used as Secondary Reinforcement?

Synthetic fibers which meet certain hardened concrete criteria can be used as nonstructural temperature or secondary reinforcement. These fibers should have documentation confirming their ability to hold concrete together after cracking.

The uniform distribution of synthetic fibers throughout the concrete ensures the critical positioning of secondary reinforcement.

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1. ASTM C 1116 Standard Specification Fiber Reinforced Concrete and Shotcrete.
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3. ASTM C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).
4. Non-structural Cracks in Concrete, Concrete Society Technical Report No. 22.
5. ICBO Evaluation Service, Inc., Acceptance Criteria for Concrete with Synthetic Fibers, January 1993.

APPLICATION GUIDELINES

Do Use Synthetic Fibers For:

- The reduction of concrete cracking as a result of plastic shrinkage.
- An alternate system of nonstructural secondary and/or temperature reinforcement.
- Greater impact, abrasion, and shatter resistance in concrete.
- Internal support and cohesiveness; the concrete for steep inclines, shotcrete, and slipformed placements.
- The reduction of concrete cracking as a result of plastic settlement.
- To help lower the permeability of concrete.
- Placements where nonmetallic materials are required.
- Areas requiring materials that are both alkali proof and chemical resistant.

Do Not Use Synthetic Fibers For:

- The control of cracking as a result of external forces.
- Higher structural strength development.
- Replacement of any moment-resisting or structural steel reinforcement.
- Decreasing the thickness of slabs on grade.
- The elimination or reduction of curling and/or creep.
- Increasing of ACI or PCA control joint guidelines.
- The justification for a reduction in the size of the support columns.
- The thinning out of bonded or unbonded overlay sections.

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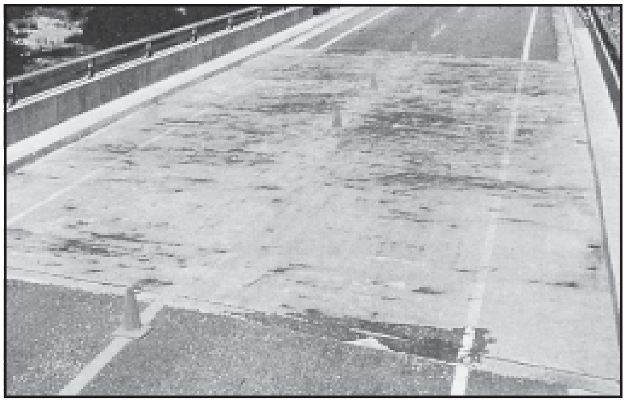
CIP 25 - Corrosion of Steel in Concrete



WHAT is Corrosion of Steel?

ASTM terminology (G 15) defines corrosion as "the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties." For steel embedded in concrete, corrosion results in the formation of rust which has two to four times the volume of the original steel and none of its good mechanical properties. Corrosion also produces pits or holes in the surface of reinforcing steel, reducing strength capacity as a result of the reduced cross-sectional area.

WHY is Corrosion of Steel a Concern?

Reinforced concrete uses steel to provide the tensile properties that are needed in structural concrete. It prevents the failure of concrete structures which are subjected to tensile and flexural stresses due to traffic, winds, dead loads, and thermal cycling. However, when reinforcement corrodes, the formation of rust leads to a loss of bond between the steel and the concrete and subsequent delamination and spalling. If left unchecked, the integrity of the structure can be affected. Reduction in the cross-sectional area of steel reduces its strength capacity. This is especially detrimental to the performance of tensioned strands in prestressed concrete.

WHY Does Steel in Concrete Corrode?

Steel in concrete is usually in a noncorroding, passive condition. However, steel-reinforced concrete is often used in severe environments where sea water or deicing salts are present. When chloride moves into the concrete, it disrupts the passive layer protecting the steel, causing it to rust and pit.

Carbonation of concrete is another cause of steel corrosion. When concrete carbonates to the level of the steel rebar, the normally alkaline environment, which protects steel from corrosion, is replaced by a more neutral environment. Under these conditions the steel is not passive and rapid corrosion begins. The rate of corrosion due to carbonated concrete cover is slower than chloride-induced corrosion.

Occasionally, a lack of oxygen surrounding the steel rebar will cause the metal to dissolve, leaving a low pH liquid.

HOW to Prevent Corrosion?

Quality Concrete—Concrete Practices

The first defense against corrosion of steel in concrete is quality concrete and sufficient concrete cover over the reinforcing bars. Quality concrete has a water-to-cementitious material ratio (w/c) that is low enough to slow down the penetration of chloride salts and the development of carbonation. The w/c ratio should be less than 0.50 to slow the rate of carbonation and less than 0.40 to minimize chloride penetration. Concretes with low w/c ratios can be produced by (1) increasing the cement content; (2) reducing the water content by using water reducers and superplasticizers; or (3) by using larger amounts of fly ash, slag, or other cementitious materials. Additionally, the use of concrete ingredients containing chlorides should be limited. The ACI 318 Building Code provides limits on the maximum amount of soluble chlorides in the concrete mix.

Another ingredient for good quality concrete is air entrainment. It is necessary to protect the concrete from freezing and thawing damage. Air entrainment also reduces bleeding and the corresponding increased permeability due to the bleed channels. Spalling and scaling can accelerate corrosion damage of the embedded reinforcing bars. Proper scheduling of finishing operations is needed to ensure that the concrete does not scale, spall, or crack excessively.

The correct amount of steel will help keep cracks tight. ACI 224 helps the design engineer to minimize the formation of cracks that could be detrimental to embedded steel. In general, the maximum allowable crack widths are 0.007 inch in deicing salt environments and 0.006 inch in marine environments.

Adequate cover over reinforcing steel is also an important factor. Chloride penetration and carbonation will occur in the outer surface of even low permeability concretes. Increasing the cover will delay the onset of corrosion. For example, the time for chloride ions to reach a steel rebar at 2 inches from the surface is four times that with a 1 inch cover. ACI 318 recommends a minimum of 1.5 inches of cover for most structures, and increases it to 2 inches of cover for protection from deicing salts. ACI 357 recommends 2.5 inches of minimum cover in marine environments. Larger aggregates require more cover. For aggregates greater than $^3/_4$ inch, a rule of thumb is to add to the nominal maximum aggregate size $^3/_4$ inch of cover for deicing salt exposure, or 1-$^3/_4$ inch of cover for marine exposure. For example, concrete with 1 inch aggregate in a marine exposure should have a 2-$^3/_4$ inch minimum cover.

The concrete must be adequately consolidated and cured. Moist curing for a minimum of seven days at 70°F is needed for concrete with a 0.40 w/c ratio, whereas six months is needed for a 0.60 w/c ratio to obtain equivalent performance. Numerous studies show that concrete porosity is reduced significantly with increased curing times and, correspondingly, corrosion resistance is improved.

Modified Concretes and Corrosion Protection Systems

Increased corrosion resistance can also come about by the use of concrete additives. Silica fume, fly ash, and blast-furnace slag reduce the permeability of the concrete to the penetration of chloride ions. Corrosion inhibitors, such as calcium nitrite, act to prevent corrosion in the presence of chloride ions. In all cases, they are added to quality concrete at w/c less than or equal to 0.45.

Water repellents may reduce the ingress of moisture and chlorides to a limited extent. However, ACI 222 indicates that these are not effective in providing long-term protection. Since good quality concrete already has a low permeability, the additional benefits of water repellents are not as significant.

Other protection techniques include protective membranes, cathodic protection, epoxy-coated reinforcing bars, and concrete sealers (if reapplied every four to five years).

References

1. "Building Code Requirements for Reinforced Concrete," ACI 318, American Concrete Institute, Farmington Hills, MI.
2. "Corrosion of Metals in Concrete," American Concrete Institute, Farmington Hills, MI.
3. "Control of Cracking in Concrete Structures," ACI 224R, American Concrete Institute, Farmington Hills, MI.
4. Design and Construction of Fixed Offshore Concrete Structures," ACI 357R, American Concrete Institute, Farmington Hills, MI.
5. Perenchio, W.F., "Corrosion of Reinforcing Steel," ASTM STP 169C, 1994, pp. 164-172.
6. Whiting, D., ed., *Paul Klieger Symposium on Performance of Concrete*, ACI SP-122, 1990, 499 pp.
7. Berke, N.S., "Corrosion Inhibitors in Concrete," *Concrete International,* Vol. 13, No. 7, 1991, pp. 24-27.
8. Berke, N.S., Pfeifer, D.W., and Weil, T.G., "Protection Against Chloride Induced Corrosion," *Concrete International, Vol.* 10, No. 12, 1988, pp. 44-55.

HOW to Limit Corrosion

1. Use good quality concrete-air entrained with a w/c of 0.40, or less.
2. Use a minimum concrete cover of 1.5 inches and at least 0.75 inch larger than the nominal maximum size of the coarse aggregate.
3. Increase the minimum cover to 2 inches for deicing salt exposure and to 2.5 inches for marine exposure.
4. Ensure that the concrete is adequately cured.
5. Use fly ash, blast-furnace slag, or silica fume and/or a proven corrosion inhibitor.

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CIP 26 - Jobsite Addition of Water

WHAT is Jobsite Addition of Water?

Jobsite addition of water is the addition of water to ready mixed concrete in a truck mixer after arrival at the location of the concrete placement. Such tempering of concrete may be done with a portion of the design mixing water which was held back during the initial mixing, or with water in excess of the design mixing water, at the request of the purchaser.

WHY is Water Added at the Jobsite?

When concrete arrives at the jobsite with a slump that is lower than that allowed by design or specification and/or is of such consistency so as to adversely affect the placeability of the concrete, water can be added to the concrete to bring the slump up to an acceptable or specified level. This can be done when the truck arrives on the jobsite as long as the specified slump and/or water-cement ratio is not exceeded. Such an addition of water is in accordance with ASTM C 94, Standard Specification for Ready Mixed Concrete.

The ready mixed concrete supplier designs the concrete mixture according to industry standards to provide the intended performance. Addition of water in excess of the design mixing water will affect concrete properties, such as reducing strength (Figure 1), and increasing its susceptibility to cracking. If the purchaser requests additional water, in excess of the design mix, the purchaser assumes responsibility for the resulting concrete quality. The alternative of using a water reducing admixture or superplacticizer to increase concrete slump should be considered. Provided segregation is avoided, increasing the slump of concrete using admixtures usually will not significantly alter concrete properties.

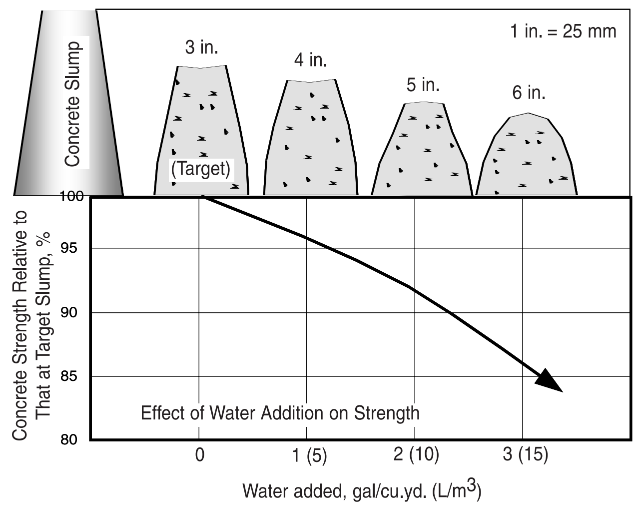

Figure 1 Example of effect of water addition on slump and strength of concrete

HOW to Add Water at the Jobsite?

a. The maximum allowable slump of the concrete must be specified or determined from the specified nominal slump plus tolerances.

b. Prior to discharging concrete on the job, the actual slump of the concrete must be estimated or determined. If the slump is measured, it should be on a sample from the first 1/4 cu. yd. (0.2 m^3) of discharged concrete and the result used as an indicator of concrete consistency and not an acceptance test. Tests for acceptance of concrete should be made in accordance with ASTM C 172.

c. At the jobsite, water should be added to the entire batch so that the volume of concrete being retempered is known. A rule of thumb that works reasonably well is—1 gallon, or roughly 10 lb., of water per cubic yard for 1 inch increase in slump (5 liters, or 5 kg, of water per cubic meter for 25 mm increase in slump).

d. All water added to the concrete on the jobsite must be measured and recorded.

e. ASTM C 94 requires an additional 30 revolutions of the mixer drum at mixing speed after the addition of water. In fact, 10 revolutions will be sufficient if the truck is able to mix at 20 revolutions per minute (rpm) or faster.

f. The amount of water added should be controlled so that the maximum slump and/or water-cement ratio, as indicated in the specification, is not exceeded. After more than a small portion of the concrete is discharged, no water addition is permitted.

g. Upon obtaining the desired slump and/or maximum water-cement ratio, no further addition of water on the jobsite is permitted.

h. A pre-concreting conference should be held to establish proper procedures to be followed, to determine who is authorized to request a water addition, and to define the method to be used for documentation of water added at the jobsite.

References

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2. NRMCA Publication 186, *"Ready Mixed Concrete"* Richard D. Gaynor, Silver Spring, Maryland.
3. NRMCA QC2—Appendix on Agenda for a Pre-Placement Conference, Silver Spring, Maryland.
4. NRMCA Publication 188, *'Truck Mixer Driver's Manual,'* Silver Spring, Maryland.
5. "Adding Water to the Mix: It's Not all Bad," Eugene O. Goeb, *Concrete Products,* January 1994.
6. "Adjusting Slump in the Field," Bruce A. Suprenant, *Concrete Construction,* January 1994.
7. "Effect of Prolonged Mixing on the Compressive Strength of Concrete with Fly Ash and/or Chemical Admixtures," Dan Ravina, submitted for publication, ACI Concrete International, 1995.

ASTM C 94 Jobsite Water Addition

1. Establish the maximum allowable slump and water content permitted by the job specification.
2. Estimate or determine the concrete slump from the first portion of concrete discharged from the truck.
3. Add an amount of water such that the maximum slump or water-cement ratio according to the specification is not exceeded.
4. Measure and record the amount of water added. Water in excess of that permitted above should be authorized by a designated representative of the purchaser.
5. Mix the concrete for 30 revolutions of the mixer drum at mixing speed.
6. Do not add water if:
   a. the maximum water-cement ratio is reached,
   b. the maximum slump is obtained, or
   c. more than 1/4 cu.yd. (0.2 m^3) has been discharged from the mixer.

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CIP 27 - Cold Weather Concreting

WHAT is Cold Weather?

Cold weather is defined as a period when the average daily temperature falls below 40°F [4°C] for more than three successive days. These conditions warrant special precautions when placing, finishing, curing and protecting concrete against the effects of cold weather. Since weather conditions can change rapidly in the winter months, good concrete practices and proper planning are critical.

WHY Consider Cold Weather?

Successful cold-weather concreting requires an understanding of the various factors that affect concrete properties.

In its plastic state, concrete will freeze if its temperature falls below about 25°F [-4°C]. If plastic concrete freezes, its potential strength can be reduced by more than 50% and its durability will be adversely affected. Concrete should be protected from freezing until it attains a minimum compressive strength of 500 psi [3.5 MPa], which is about two days after placement for most concrete maintained at 50°F [10°C].

Low concrete temperature has a major effect on the rate of cement hydration, which results in slower setting and rate of strength gain. A good rule of thumb is that a drop in concrete temperature by 20°F [10°C] will approximately double the setting time. The slower rate of setting and strength gain should be accounted for when scheduling construction operations, such as form removal.

Concrete in contact with water and exposed to cycles of freezing and thawing, even if only during construction, should be air-entrained. Newly placed concrete is saturated with water and should be protected from cycles of freezing and thawing until it has attained a compressive strength of at least 3500 psi [24.0 MPa].

Cement hydration is a chemical reaction that generates heat. Newly placed concrete should be adequately insulated to retain this heat and thereby maintain favorable curing temperatures. Large temperature differences between the surface and the interior of the concrete mass should be prevented as cracking may result when this difference exceeds about 35°F [20°C]. Insulation or protective measures should be gradually removed to avoid thermal shock.

HOW to Place Concrete in Cold Weather?

Recommended concrete temperatures at the time of placement are shown below. The ready mixed concrete producer can control concrete temperature by heating the mixing water and/or the aggregates and furnish concrete in accordance with the guidelines in ASTM C 94.

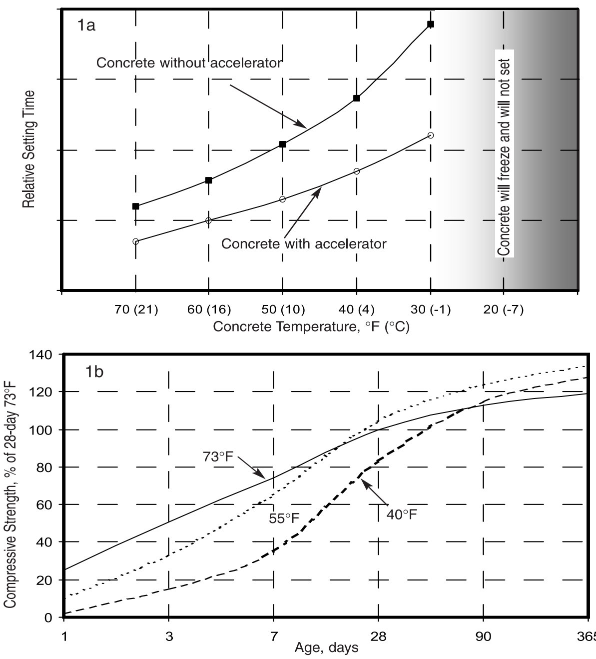

Figure 1 Effect of Temperature on Set Time (1a)

Section Size, minimum dimension, inch [mm]	Concrete temperature as placed
less than 12 [300]	55°F [13°C]
12 - 36 [300 - 900]	50°F [10°C]
36 - 72 [900 - 1800]	45°F [7°C]

Cold weather concrete temperature should not exceed these recommended temperatures by more than 20°F [10°C]. Concrete at a higher temperature requires more mixing water, has a higher rate of slump loss, and is more susceptible to cracking. Placing concrete in cold weather provides the opportunity for better quality, as cooler initial concrete temperature will typically result in higher ultimate strength.

Slower setting time and strength gain of concrete during cold weather typically delays finishing operations and form removal. Chemical admixtures and other modifications to the concrete mixture can accelerate the rate of setting and strength gain. Accelerating chemical admixtures, conforming to

ASTM C 494—Types C (accelerating) and E (water-reducing and accelerating), are commonly used in the winter time. Calcium chloride is a common and effective accelerating admixture, but should not exceed a maximum dosage of 2% by weight of cement. Non-chloride, non-corrosive accelerators should be used for prestressed concrete or when corrosion of steel reinforcement or metal in contact with concrete is a concern. Accelerating admixtures do not prevent concrete from freezing and their use does not preclude the requirements for concrete temperature and appropriate curing and protection from freezing.

Accelerating the rate of set and strength gain can also be accomplished by increasing the amount of portland cement or by using a Type III cement (high early strength). The relative percentage of fly ash or ground slag in the cementitious material component may be reduced in cold weather but this may not be possible if the mixture has been specifically designed for durability. The appropriate decision should afford an economically viable solution with the least impact on the ultimate concrete properties.

Concrete should be placed at the lowest practical slump as this reduces bleeding and setting time. Adding 1 to 2 gallons of water per cubic yard [5 to 10 L/m^3] will delay set time by ½ to 2 hours. Retarded set times will prolong the duration of bleeding. Do not start finishing operations while the concrete continues to bleed as this will result in a weak surface.

Adequate preparations should be made prior to concrete placement. Snow, ice and frost should be removed and the temperature of surfaces and metallic embedments in contact with concrete should be above freezing. This might require insulating or heating subgrades and contact surfaces prior to placement.

Materials and equipment should be in place to protect concrete, both during and after placement, from early age freezing and to retain the heat generated by cement hydration. Insulated blankets and tarps, as well as straw covered with plastic sheets, are commonly used measures. Enclosures and insulated forms may be needed for additional protection depending on ambient conditions. Corners and edges are most susceptible to heat loss and need particular attention. Fossil-fueled heaters in enclosed spaces should be vented for safety reasons and to prevent carbonation of newly placed concrete surfaces, which causes dusting.

The concrete surface should not be allowed to dry out while it is plastic as this causes plastic shrinkage cracks. Subsequently, concrete should be adequately cured. Water curing is not recommended when freezing temperatures are imminent. Use membrane-forming curing compounds or impervious paper and plastic sheets for concrete slabs.

Forming materials, except for metals, serve to maintain and evenly distribute heat, thereby providing adequate protection in moderately cold weather. With extremely cold temperatures, insulating blankets or insulated forms should be used, especially for thin sections. Forms should not be stripped for 1 to 7 days depending on the setting characteristics, ambient conditions and anticipated loading on the structure. Field-cured cylinders or nondestructive methods should be used to estimate in-place concrete strength prior to stripping forms or applying loads. Field-cured cylinders should not be used for quality assurance.

Special care should be taken with concrete test specimens used for acceptance of concrete. Cylinders should be stored in insulated boxes, which may need temperature controls, to insure that they are cured at 60°F to 80°F [16°C to 27°C] for the first 24 to 48 hours. A minimum/maximum thermometer should be placed in the curing box to maintain a temperature record.

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2. *Design and Control of Concrete Mixtures*, Portland Cement Association, Skokie, IL.
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Cold Weather Concreting Guidelines

1. Use air-entrained concrete when exposure to moisture and freezing and thawing conditions are expected.
2. Keep surfaces in contact with concrete free of ice and snow and at a temperature above freezing prior to placement.
3. Place and maintain concrete at the recommended temperature.
4. Place concrete at the lowest practical slump.
5. Protect plastic concrete from freezing or drying.
6. Protect concrete from early-age freezing and thawing cycles until it has attained adequate strength.
7. Limit rapid temperature changes when protective measures are removed.

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CIP 28 - Concrete Slab Moisture

WHAT is the Problem?

Concrete slab moisture can cause problems with the adhesion of floor-covering material, such as tile, sheet flooring, or carpet and bond-related failures of non-breathable floor coatings. Many adhesives used for installation of floor coverings are more water-sensitive than in the past, due to restrictions on the use of volatile organic compounds (VOCs). To warranty their products, manufacturers require that the moisture emission from the hardened concrete slab be less than some threshold value prior to installing floor coverings or coatings. Fast-track construction schedules exacerbate the problem when floor-surfacing material is installed before the concrete slab has dried to an acceptable level.

WHAT are the Sources of Concrete Slab Moisture?

a Ground water sources and when the floor slab is in contact with saturated ground, or if drainage is poor. Moisture moves to the slab surface by capillary action or wicking. Factors affecting this include depth of the water table and fineness of soil below the slab. Fine grained soil promotes moisture movements from considerable depths compared to coarser subgrade material.

b Water vapor from damp soil will diffuse and condense on a concrete slab surface that is cooler and at a lower relative humidity due to a vapor pressure gradient.

c Wetting of the fill course/blotter layer, if any, between the vapor retarder and the slab prior to placing the slab will trap moisture with the only possible escape route being through the slab. A blotter layer is not recommended for interior slabs on grade (CIP 29).

d Residual moisture in the slab from the original concrete mixing water will move towards the surface. It may take anywhere from six weeks to one year or longer for a concrete slab to dry to an acceptable level under normal conditions, as illustrated in Figure 1. Factors that affect the drying rate include the original water content of the concrete, type of curing, and the relative humidity and temperature of the ambient air during the drying period. This is the only source of moisture in elevated slabs. Any wetting of the slab after final curing will elevate moisture levels within the slab and lengthen the drying period.

HOW do You Avoid Problems?

Avoiding problems associated with high moisture content in concrete can be accomplished by the following means:

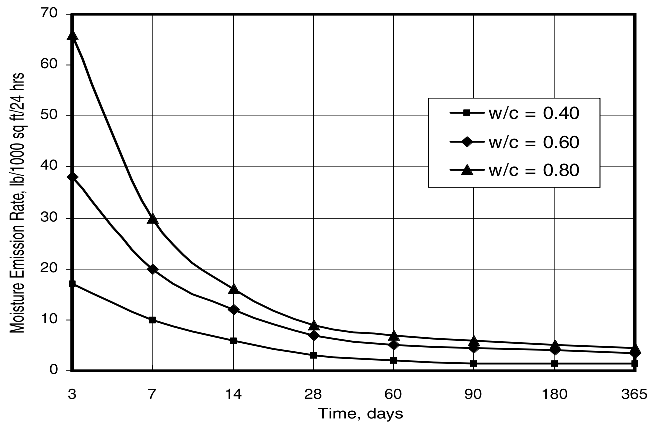

Figure 1 Drying rate of concretes sealed at the bottom (ref 3)

- Protect against ingress of water under hydrostatic pressure by ensuring that proper drainage away from the slab is part of the design.
- Use a 6 to 8 inch [150 to 200 mm] layer of coarse gravel or crushed stone as a capillary break in locations with fine-grained soil subgrades.
- Use a vapor retarder membrane under the slab to prevent water from entering the slab. Ensure that the vapor retarder is installed correctly and not damaged during construction. Current recommendation of ACI Committee 302 is to place the concrete directly on a vapor retarder for interior slabs on grade (CIP 29).
- Use a concrete mixture with a moderately low water-cementitious material (w/cm) ratio (about 0.50). This reduces the amount of residual moisture in the slab, will require a shorter drying period, and result in a lower permeability to vapor transmission. Water reducing admixtures can be used to obtain adequate workability and maintain a low water content. The water tightness of concrete can be improved by using fly ash or slag in the concrete mixture.
- Curing is an important step in achieving excellent hardened concrete properties. However, moist curing will increase drying time. As a compromise, curing the concrete under plastic sheeting for 3 days is recommended and moist curing times greater than 7 days must be avoided. Avoid using curing compounds on floors where coverings or coatings will be installed.
- Allow sufficient time for the moisture in the slab to dry naturally while the floor is under a roof and protected from the elements.

Avoid maintenance and cleaning operations that will wet the concrete floor. Use heat and dehumidifiers to accelerate drying. Since moisture transmission is affected by temperature and humidity, maintain the actual service conditions for a long enough period prior to installing the floor covering.

- Test the slab moisture condition prior to installing the floor covering.

When concrete slab moisture cannot be controlled, consider using decorative concrete, less moisture-sensitive floor coverings, breathable floor coatings, or install moisture vapor suppression systems (topical coatings).

HOW is Concrete Slab Moisture Measured?

Various qualitative and quantitative methods of measuring concrete slab moisture are described in ASTM E 1907. Test the moisture condition of the slab in the same temperature and humidity conditions as it will be in service. In general, test at three random sample locations for areas up to 1000 sq. ft. [100 m^2] and perform one additional test for each additional 1,000 sq ft. Ensure that the surface is dry and clean. Record the relative humidity and temperature at the time of testing. Some of the common tests are:

Polyethylene Sheet Test (ASTM D 4263) - is a simple qualitative test, where an 18 by 18 inch [450 by 450 mm] square plastic sheet is taped tightly to the concrete and left in place for a at least 16 hours. The presence of moisture under the plastic sheet is a positive indication that excess moisture is likely present in the slab. However, a negative indication is not an assurance that the slab is acceptably dry below the surface.

Mat Test - where the adhesive intended for use is applied to a 24 by 24 inch [600 by 600 mm] area and a sheet vinyl flooring product is placed face down on the adhesive and sealed at the edges. A visual inspection of the condition of the adhesive is made after a 72-hour period. This test is no longer favored since it can produce false negative results.

Test Strip – in which a test strip of the proposed primer or adhesive is evaluated for 24 hours to predict its behavior on the floor. This procedure is not very reliable.

Moisture meters – Measure electrical resistance or impedance to indicate slab moisture. Electronic meters can be useful survey tools that provide comparative readings across a floor but should not be used to accept or reject a floor because they do not provide an absolute measure of moisture conditions within the slab.

Gravimetric - This is a direct and accurate method of determining moisture content by weight in the concrete slab. Pieces of concrete are removed by chiseling or stitch-drilling and dried in an oven to constant weight. The moisture content is then calculated as a percentage of the dry sample weight. This is rarely recommended by floor covering manufacturers.

Nuclear Density and Radio Frequency - This nondestructive test instrument is relatively expensive and can take a long time to properly correlate correction factors for each individual project. The instrument has a radioactive source and therefore requires licensed operators.

Anhydrous Calcium Chloride Test (ASTM F 1869) - is specified by most floor covering manufacturers for pre installation testing. A measured amount of anhydrous calcium chloride is placed in a cup sealed under a plastic dome on the slab surface and the amount of moisture absorbed by the salt in 60 to 72 hours is measured to calculate the moisture vapor emission rate (MVER). Maximum limits of vapor transmission generally specified are 3 to 5 pounds of moisture per 1000 square feet per 24 hours. This test is relatively inexpensive, and yields a quantitative result. However, it has some major shortcomings: it determines only a portion of the free moisture at a shallow depth of concrete near the surface of the slab. The test is sensitive to the temperature and humidity in the building. It provides only a "snapshot in time" of current moisture conditions and does not predict if the sub-slab conditions will cause a moisture problem later in the life of the floor.

Relative Humidity Probe (ASTM F 2170) – This procedure involves measuring the relative humidity of concrete at a specific depth from the slab surface inside a drilled or cast hole in a concrete slab. The relative humidity is measured after allowing 72 hours to achieve moisture equilibrium within the hole. Typically a relative humidity of 75% to 80% is targeted for installation of floor coverings. Relative humidity probes can determine the moisture profile from top to bottom in a slab, conditions below the slab, and can monitor the drying of a slab over time, leading to predictions of future moisture conditions. These instruments have been used for many years in Europe and are becoming more popular in the United States.

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CIP 29 - Vapor Retarders Under Slabs on Grade

WHAT are Vapor Retarders?

Vapor retarders are materials that will minimize the transmission of water vapor from the sub-slab support system into a concrete slab. Vapor retarders are typically specified according to ASTM E 1745 and have a permeance of less than 0.3 US perms (0.2 metric perms), when tested by ASTM E 96. Low-density polyethylene film is commonly used and a minimum thickness of 10 mils (0.25 mm) is recommended for reduced vapor transmission and durability during and after its installation. Membrane material specifically designed for use as true vapor barriers with permeance ratings of 0.0 perms per square foot per hour, as measured by ASTM E 96, are also available.

WHY are Vapor Retarders Used?

Vapor retarders are frequently specified for interior concrete slabs on grade where moisture protection is desired. Protection from moisture is required when floors will be covered with carpet, tile, wood, resilient, and seamless polymeric flooring, or when moisture-sensitive equipment or products will be placed on the floor. Permeation of water vapor through concrete slabs can cause failure of moisture-sensitive adhesives or coatings resulting in delamination, distortion or discoloration of flooring products, trip-and-fall hazards, and possibly fungal growth and odors.

Low-permeability membranes below floor slabs on grade, in conjunction with sealed joints, also provide a barrier to radon penetration into enclosed spaces when such conditions exist.

WHAT Conditions Require Vapor Retarders?

A floor is part of the building envelope and should be constructed to eliminate moisture infiltration into the slab and into the occupied building space. For many years, vapor retarders were specified only for floor slabs intended to receive floor coverings. However, even floors intended for "bare" use in service, such as warehouses, mechanical rooms, and unfinished expansion areas, often are converted to other uses and then moisture-sensitive flooring is installed. Such "adaptive re-use" cannot be predicted during design and construction of a new building. Therefore, it is sensible planning to include a vapor retarder under every interior floor slab in every building. Vapor retarders are generally not necessary when placing exterior slabs on grade.

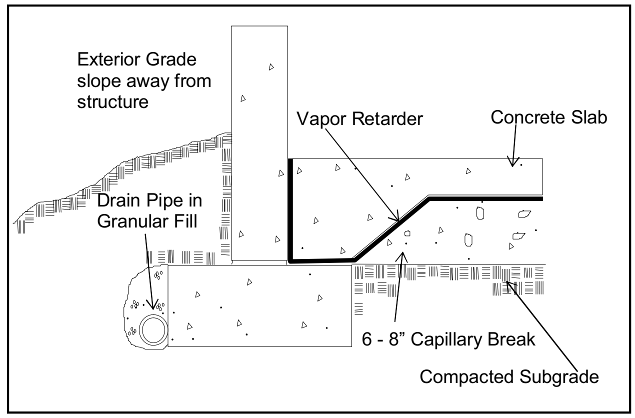

Figure 1 Typical Detail of Slab on Grade with Vapor Retarder

Vapor retarders do not prevent migration of residual moisture from within the concrete slab to the surface. It is important to use a concrete mixture with the lowest water content that will afford adequate workability. Chemical and mineral admixtures are generally used to minimize the water content in a concrete mixture and provide adequate workability for placement. After proper curing, the concrete slab should be allowed to dry out and tested to ensure that moisture is not being transmitted through the slab prior to installing flooring materials (CIP 28).

HOW to Place Concrete on Vapor Retarders?

Current recommendation of ACI Committee 302 is to place a concrete slab directly on top of a vapor retarder when the concrete slab surface will receive a vapor sensitive floor covering. If environmental conditions exist for increased possibility of plastic shrinkage cracking, placing concrete directly on the vapor retarder can help alleviate the plastic shrinkage cracking somewhat by enhancing bleed water.

Placing concrete directly on the vapor retarder can also create potential problems. If environmental conditions do not permit rapid drying of bleed water from the slab surface then the excess bleeding can delay finishing operations. Bleed water trapped below a finished surface can cause delaminations (CIP 20) or blisters (CIP 13) if finishing operations are not performed at the correct time after bleedwater has disappeared from the surface. Concrete may stiffen slower, which means that trowel finishing operations must be delayed; thus increasing the susceptibility of plastic shrinkage cracking. Curling (CIP 19) can occur due to differential drying and related shrinkage at different levels in the slab. Most of these problems can be alleviated by using a concrete with a low water content, moderate cement factor, and well-graded aggregate with the largest possible size. With the increased occurrence of moisture related floor covering failures, minor cracking of floors placed on a vapor retarder and other problems discussed here are considered a more acceptable risk than failure of floor coverings.

The sub-grade and base should be adequately compacted. The base should be well draining and stable to support construction traffic. A clean fine-graded, preferably crushed, material with about 10 to 30 percent passing the No. 100 [150-mm] sieve and free of clay or organic material is generally recommended. Concrete sand should not be used as it is easily displaced during construction.

If recommended in the geotechnical evaluation of the jobsite, install a 6 to 8 inch [150 to 200 mm] layer of coarse gravel or crushed stone as a capillary break. Note that a coarse stone capillary break will not reduce moisture vapor transmission from the subgrade. A vapor retarder is still required above a capillary break.

If a capillary break layer of coarse stone is used, choke the top surface with 2-in. of graded, fine-grained compactable fill to prevent damage to the vapor retarder from sharp corners of the coarse stone. Place the vapor retarder on top of the smooth, compacted fill.

Vapor retarder sheets should be overlapped by 6 inches [150 mm] at the seams and taped and sealed around utility or column openings, grade beams, footings, and foundation walls.

If an interior concrete slab will not have a vapor-sensitive floor covering but will be located in a humidity controlled area it may be placed over the granular fill/blotter layer provided the slab and base material is placed with waterproof roof membrane in place. Further the granular material should not be subject to future moisture infiltration.

When the choice is made to place the concrete over a granular blotter layer, a minimum 4 inch [100 mm] layer of compactable, easy-to-trim, granular fill material should be used. A "crusher-run" material graded from 1½ in. [37.5 mm] to dust size works well. If this is not practical, cover the vapor retarder with at least 3 inches [75 mm] of crushed stone sand. Do not use concrete sand. To reduce slab friction, top off the crusher-run layer with a layer of fine-graded material. The granular layer should ideally be placed under cover and should be dry prior to concrete placement to function as a blotter and remove water from the fresh concrete.

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Follow These Rules When Using Vapor Retarders

1. Provide a vapor retarder directly under all interior floor slabs.
2. Place the vapor retarder on a smooth base and ensure it is vapor tight to moisture sources below the slab and at its edges and at penetrations.
3. Order a concrete mixture designed for minimum shrinkage and follow good concrete practices for finishing and curing to reduce potential water vapor emission. If the concrete slab will receive a vapor-sensitive floor covering, cure the concrete under plastic sheeting for 3 days and in no case moist cure the concrete for more than 7 days.

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CIP 30 - Supplementary Cementitious Materials

WHAT are Supplementary Cementitious Materials?

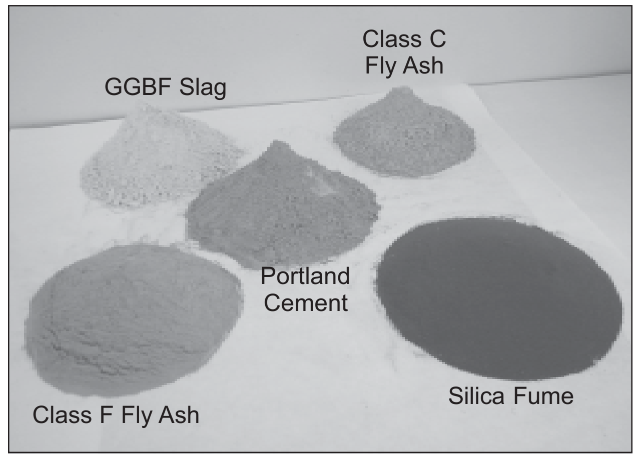
In its most basic form, concrete is a mixture of portland cement, sand, coarse aggregate and water. The principal cementitious material in concrete is portland cement. Today, most concrete mixtures contain supplementary cementitious materials that make up a portion of the cementitious component in concrete. These materials are generally byproducts from other processes or natural materials. They may or may not be further processed for use in concrete. Some of these materials are called pozzolans, which by themselves do not have any cementitious properties, but when used with portland cement, react to form cementitious compounds. Other materials, such as slag, do exhibit cementitious properties.

For use in concrete, supplementary cementitious materials, sometimes referred to as mineral admixtures, need to meet requirements of established standards. They may be used individually or in combination in concrete. They may be added to the concrete mixture as a blended cement or as a separately batched ingredient at the ready mixed concrete plant.

Some examples of these materials are listed below.

Fly Ash is a byproduct of coal-fired furnaces at power generation facilities and is the non-combustible particulates removed from the flue gases. Fly ash used in concrete should conform to the standard specification, ASTM C 618. The amount of fly ash in concrete can vary from 5% to 65% by mass of the cementitious materials, depending on the source and composition of the fly ash and the performance requirements of the concrete. Characteristics of fly ash can vary significantly depending on the source of the coal being burnt. Class F fly ash is normally produced by burning anthracite or bituminous coal and generally has a low calcium content. Class C fly ash is produced when subbituminous coal is burned and typically has cementitious and pozzolanic properties.

Ground Granulated Blast Furnace Slag (GGBFS) is a non-metallic manufactured byproduct from a blast furnace when iron ore is reduced to pig iron. The liquid slag is rapidly cooled to form granules, which are then ground to a fineness similar to portland cement. Ground granulated blast furnace slag used as a cementitious material should conform to the standard specification, ASTM C 989. Three grades - 80, 100, and 120 are defined in C 989, with the higher grade contributing more to strength potential. GGBFS has cementitious properties by itself but these are enhanced when it is used with portland cement. Slag is used at 20% to 70% by mass of the cementitious materials.



Silica Fume is a highly reactive pozzolanic material and is a byproduct from the manufacture of silicon or ferro-silicon metal. It is collected from the flue gases from electric arc furnaces. Silica fume is an extremely fine powder, with particles about 100 times smaller than an average cement grain. Silica fume is available as a densified powder or in a water-slurry form. The standard specification for silica fume is ASTM C 1240. It is generally used at 5 to 12% by mass of cementitious materials for concrete structures that need high strength or significantly reduced permeability to water. Due to its extreme fineness special procedures are warranted when handling, placing and curing silica fume concrete.

Natural Pozzolans. Various naturally occurring materials possess, or can be processed to possess pozzolanic properties. These materials are also covered under the standard specification, ASTM C 618. Natural pozzolans are generally derived from volcanic origins as these siliceous materials tend to be reactive if they are cooled rapidly. In the US, commercially available natural pozzolans include, **metakaolin** and **calcined shale or clay**. These materials are manufactured by controlled calcining (firing) of naturally occurring minerals. Metakaolin is produced from relatively pure kaolinite clay and it is used at 5% to 15% by mass of the cementitious materials. Calcined shale or clay is used at higher percentages by mass. Other natural pozzolans include **volcanic glass, zeolitic trass or tuffs, rice husk ash and diatomaceous earth.**

WHY are Supplementary Cementitious Materials Used?

Supplementary cementitious materials can be used for improved concrete performance in its fresh and hardened state. They are primarily used for improved workability, durability and strength. These materials allow the concrete producer to design and modify the concrete mixture to suit the desired application. Concrete mixtures with high portland cement contents are susceptible to cracking and increased heat generation. These effects can be controlled to a certain degree by using supplementary cementitious materials.

Supplementary cementitious materials such as fly ash, slag and silica fume enable the concrete industry to use hundreds of millions of tons of byproduct materials that would otherwise be landfilled as waste. Furthermore, their use reduces the consumption of portland cement per unit volume of concrete. Portland cement has a high energy consumption and emissions associated with its manufacture, which is conserved or reduced when the amount used in concrete is reduced.

HOW do these Materials Affect Concrete Properties?

Fresh Concrete: In general, supplementary cementitious materials improve the **consistency** and **workability** of fresh concrete because an additional volume of fines is added to the mixture. Concrete with silica fume is typically used at low water contents with high range water reducing admixtures and these mixtures tend to be cohesive and stickier than plain concrete. Fly ash and slag generally reduce the water demand for required concrete slump. Concrete **setting time** may be retarded with some supplementary cementitious materials used at higher percentages. This can be beneficial in hot weather. The retardation is offset in winter by reducing the percentage of supplementary cementitious material in the concrete. Because of the additional fines, the amount and rate of **bleeding** of these concretes is often reduced. This is especially significant when silica fume is used. Reduced bleeding, in conjunction with retarded setting, can cause plastic shrinkage cracking and may warrant special precautions during placing and finishing. (See CIP 5)

Strength - Concrete mixtures can be proportioned to produce the required strength and rate of strength gain as required for the application. With supplementary cementitious materials other than silica fume, the rate of strength gain might be lower initially, but strength gain continues for a longer period compared to mixtures with only portland cement, frequently resulting in higher ultimate strengths. Silica fume is often used to produce concrete compressive strengths in excess of 10,000 psi [70 MPa]. Concrete containing supplementary cementitious material generally needs additional consideration for curing of both the test specimens and the structure to ensure that the potential properties are attained.

Durability - Supplementary cementitious materials can be used to reduce the heat generation associated with cement hydration and reduce the potential for thermal cracking in massive structural elements. These materials modify the microstructure of concrete and reduce its permeability thereby reducing the penetration of water and water-borne salts into concrete. Watertight concrete will reduce various forms of concrete deterioration, such as corrosion of reinforcing steel and chemical attack. Most supplementary cementitious materials can reduce internal expansion of concrete due to chemical reactions such as alkali aggregate reaction and sulfate attack. Resistance to freezing and thawing cycles requires the use of air entrained concrete. Concrete with a proper air void system and strength will perform well in these conditions.

The optimum combination of materials will vary for different performance requirements and the type of supplementary cementitious materials. The ready mixed concrete producer, with knowledge of the locally available materials, can establish the mixture proportions for the required performance. Prescriptive restrictions on mixture proportions can inhibit optimization and economy. While several enhancements to concrete properties are discussed above, these are not mutually exclusive and the mixture should be proportioned for the most critical performance requirements for the job with the available materials.

References

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3. *Use of Fly Ash in Concrete*, ACI 232.2R, American Concrete Institute, Farmington Hills, MI.
4. *Ground Granulated Blast Furnace Slag as a Cementitious Constituent in Concrete*, ACI 233R, American Concrete Institute, Farmington Hills, MI.
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CIP 31 - Ordering Ready Mixed Concrete

WHAT is Ready Mixed Concrete?

Concrete is a mixture of cementitious materials, water, aggregate, usually sand and gravel or crushed stone. There is a common misunderstanding that cement and concrete are one and the same. Cement is a powdered ingredient that provides the glue that binds the aggregates together in a mass called concrete.

Ready mixed concrete is that which is delivered to the customer in a freshly mixed and unhardened state. Due to the ability to customize its properties for different applications and its strength and durability to withstand a wide variety of environmental conditions, ready mixed concrete is one of the most versatile and popular building materials.

Concrete mixtures are proportioned to obtain the required properties for the application. It should have the correct consistency, or slump, to facilitate handling and placing and adequate strength and durability to withstand applied loads in the anticipated environment and service conditions. The design quantities of concrete ingredients are accurately weighed and mixed, either in a mixer at the concrete plant or in a concrete truck mixer. It is delivered in a truck mixer or agitation unit, which keeps the concrete uniformly mixed until it is discharged at the placement location. Concrete remains plastic for several hours depending on the type of mixture and conditions during placement so that there is sufficient time for it to be placed and finished. Concrete normally sets or hardens within two to twelve hours after mixing and continues to gain strength for months or even years if it is properly cured during the first few days.

WHY Use Ready Mixed Concrete?

Concrete, in its freshly mixed state, is a plastic workable mixture that can be cast into virtually any desired shape. The properties of concrete can be customized for almost any application to serve in a wide variety of extreme environments. Concrete is a very economical building material that can serve its function for several years with minimum maintenance, provided the proper mixture relative to the application and established construction practices are used. A wide variety of options with color, texture and architectural detail are available to enhance the aesthetic quality of the concrete application.

HOW to Order Ready Mixed Concrete?

The key to placing an order for ready mixed concrete is to provide all the basic detailed information and to keep the requirements as simple as possible and relevant to the application. The ready mixed concrete producer has several mixture formulations for a wide variety of applications and can help with deciding the required mixture characteristics.

Some of the basic requirements to keep in mind when placing a concrete order are as follows:

Size of coarse aggregate - the important information is the nominal maximum size required, which should be smaller than the narrowest dimension through which concrete should flow, such as the thickness of the section and spacing of the reinforcing steel, if any. For most applications, nominal maximum size of coarse aggregate is $^{3}/_{4}$ or 1 inch (19.0 or 25.0 mm).

Slump - Concrete slump, a measure of its consistency, should be indicated. A stiffer mixture will have a low slump value. Typical slump range for most applications is 3 to 5 inches (75 to 100 mm). For slip-form construction a maximum slump of 2 inches (50 mm) is required, while higher slump to a maximum of 7 inches (175 mm) is typical for basement walls. The tolerance on the slump as delivered is ±1 to $1^{1}/_{2}$ inch (25 to 38 mm). Addition of water at the jobsite to increase slump is permitted, provided it is not excessive enough to cause segregation and reduce strength and durability.

Entrained air - Air entrained concrete should be used if concrete will be exposed to freezing temperatures in service, or even during construction. In many locations air-entrained concrete is the default option. When non air-entrained concrete is required this should be clearly stated at the time of ordering. Target air content depends on the size of the coarse aggregate and the typical range is 4 to 6% of the concrete volume. The tolerance on air content as delivered is ±1.5%. The concrete supplier is permitted to make an adjustment for air content at the jobsite if, when tested it is lower than the required amount.

Quality level required - The purchaser specifies the concrete quality, in terms of its properties or composition.

The preferred method for ordering concrete is by specifying performance requirements, which is generally the concrete strength. Other performance characteristics, such as permeability, shrinkage or various durability requirements, may be specified when required. The producer should be made aware of anticipated exposure and service conditions of the structure. The concrete producer is best equipped to proportion, mix and furnish concrete for the desired performance. The strength level is generally dictated by the design of the structure to withstand anticipated loads during construction and in service. A minimum strength of 3500 to 4000 psi (25 to 28 MPa) may ensure durable concrete, such as resistance to wear, abrasion, and freezing and thawing cycles.

Another option is to order concrete by specifying **prescriptive** requirements. The purchaser specifies limits on the quantities and types of ingredients in the mixture. In this case the purchaser should generally accept responsibility for concrete strength and performance. The prescriptive limits may indicate minimum cement content, maximum water-cement ratio, and limits on the quantities of pozzolans, slag or admixtures. Frequently, this approach is used when a particular prescriptive mixture formulation has worked well in the past. This approach does not allow the producer much flexibility on the economy of the mixture or to accommodate changes in material sources or characteristics that may affect concrete's performance.

Specifying performance and prescriptive requirements is discouraged as the performance requirements may conflict with the prescriptive limits.

Quantity of concrete - Concrete is sold by volume, in cubic yards (cubic meters), in a freshly mixed unhardened state as discharged from the truck mixer. The delivered volume, or yield, is calculated from the measured concrete density or unit weight. One cubic yard of concrete weighs about 4000 lb. (2 short tons). One cubic meter (approximately 1.3 cubic yards) weighs about 2400 kg. The typical capacity of a truck mixer is 8 to 12 cubic yards (5 to 9 cubic meters).

Order about 4% to 10% more concrete than is estimated from a volumetric calculation of the plan dimensions. This will account for waste or spillage, over-excavation, spreading of forms, loss of entrained air during placement, settlement of a wet mixture, truck mixer hold-back and change in volume - hardened concrete volume is 1% to 2% less than that of the fresh concrete. Reevaluate the needs during placement and communicate any changes to the concrete supplier.

Disposal of returned concrete has environmental and economical implications to the ready mixed concrete producer. Make a good estimate of concrete required for the job before placing an order. Avoid ordering small *clean-up* loads, less than 4 cubic yards (2.5 cubic meters).

Additional Items - A variety of value-added options are available from the ready mixed concrete producer. Chemical admixtures can accelerate or retard the setting characteristics of concrete to aid in placing and finishing during hot or cold weather. Water reducing admixtures are used to increase concrete slump without adding water to the concrete. Synthetic fibers can reduce the potential for plastic shrinkage cracking. Using color or special aggregates can enhance aesthetic characteristics. The concrete contractor can also be a resource for innovative finishes and textures to concrete.

Scheduling delivery - Schedule the delivery of concrete to accommodate the construction schedule. Inform the producer of the correct address, location and nature of the pour, and an estimated delivery time. Call the ready mixed concrete producer well in advance of the required delivery date. Concrete is a perishable product and the construction crew should be ready for concrete placement when the truck arrives. Notify the producer of any schedule changes or work stoppage immediately.

Ensure that the truck mixer has proper access to the placement location. The concrete truck weighs in excess of 60,000 lbs. (27,000 kg) and may not be able to maneuver on loose dirt and residential curbs and pathways.

WHAT are the Responsibilities?

The responsibilities of the various parties involved in the construction process should be addressed at a pre-construction meeting, especially on a large job. These responsibilities should be documented and distributed to all concerned for reference during the construction. Some items are discussed below.

- The concrete producer is responsible for the concrete slump as specified for a period of 30 minutes after the requested time or the time the truck arrives at the placement site, whichever is later.
- The concrete producer is required to deliver concrete at the requested slump and air content, within the accepted tolerances addressed above, as measured at the point of discharge from the transportation unit.
- When placing procedures can potentially alter the characteristics of the fresh concrete, it is the responsibility of the purchaser to inform the producer of changes to the mixture requirements to accommodate these effects. An example is pumping concrete in place.
- When a job uses more than one type of concrete mixture, it is the purchaser's responsibility to verify the mixture delivered and direct it to the correct placement location.
- The purchaser should check and sign the delivery ticket and document any special occurrences on the ticket.
- The concrete producer cannot be responsible for the quality of concrete when any modification or additions are made to the mixture at the jobsite. These include addition of excessive water, admixtures, fibers or special products, or if the truck has to wait for an extended period before discharging the concrete.
- When strength tests are used for acceptance of concrete, the samples should be obtained at the point of discharge from the transportation unit. The purchaser or his representative should ensure that proper facilities are available for curing the test specimens at the jobsite and that standard practices are followed for subsequent curing and testing. Certified personnel should conduct the tests. Test reports should be forwarded to the producer in a timely manner to ensure that deficiencies are rectified.

References

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2. *Ready Mixed Concrete*, Richard D. Gaynor, NRMCA Publication 186, NRMCA, Silver Spring, MD.
3. *Guide for Measuring, Mixing, Transporting and Placing Concrete*, ACI 304R, American Concrete Institute, Farmington Hills, MI

CAUTION

Fresh concrete can cause severe chemical burns to skin and eyes. Keep fresh concrete off your skin. When working with concrete use rubber work-boots, gloves, protective eyeglasses, clothing and knee-boards. Do not let concrete or other cement products soak into clothing or rub against your skin. Wash your skin promptly after contact with fresh concrete with clean water. If fresh concrete gets into your eyes, flush immediately and repeatedly with water and consult a doctor immediately. Keep children away from dry cement powder and all freshly mixed concrete.

CIP 32 - Concrete Pre-Construction Conference

WHAT is a Pre-Construction Conference?

Prior to the start of a job, especially for a major project, a concrete pre-construction conference (some times called a pre-pour meeting) should be held to define and allocate responsibilities of the entire construction team. It is imperative that all members of the team meet to establish the responsibilities of the ready mixed concrete supplier, owner, architect, structural engineer, general contractor, sub contractors, testing agencies, and inspectors. This meeting should be held well in advance of the project to ensure there is sufficient time for all parties to be absolutely clear on what their responsibilities would entail.

WHY Have a Pre-Construction Conference?

Every construction project brings together different companies, personnel and procedures, who may or may not have worked together before. Two jobs are never the same, even when working with the same companies, as personnel changes can realign the perception of individual responsibilities. Pre-construction conferences are needed to sort out the details of how a job will be executed, identify the authorized contacts for various aspects, and what should be done if some things do not go as planned. In far too many cases, projects are started without a clear understanding of assigned responsibilities resulting in extra work, lost time and major expenses. In some cases a simple pre-construction conference could have prevented some, if not all these problems from occurring. Having this meeting serves to document the chain of responsibilities, which can be referenced when needed.

HOW to Conduct a Pre-Construction Conference?

The pre-construction conference agenda should contain the following to ensure that all details are addressed prior concrete placement.

Purpose: To define and allocate individual responsibilities of the concrete construction team

Subject: Pre-construction agenda, concrete mix designs, placement, inspection and testing

Project Name and Location: Establish the project name and address.

Personnel to Attend: Contractor's project manager, owner's representative, concrete subcontractor, architect, engineer, testing lab supervisor, pumping contractor, concrete producer's quality control director, inspector and construction manager, if applicable, and anyone else with the need to know.

Minutes of the Meeting: Assign someone to take minutes. Establish a meeting distribution list.

Concrete Mix Design and Specifications: Have the mix designs been approved and what is the approval process? Are there any special concrete performance requirements or conditions? Are value-added admixtures approved for use and who can authorize them?

Ordering Concrete and Scheduling Deliveries: Ensure that concrete delivery schedules are in place. Establish the lead-time needed to place the order, especially for large placements or special concrete, and establish links of communication for last minute cancellations. Establish who has the authority to place and cancel concrete orders. Establish truck staging areas and location to wash out trucks and disposing of excess concrete.

Plant Inspections: Are plant inspections required? If so who will do the inspections and what will it entail. Will an NRMCA certification be accepted?

Job Inspections: Who is responsible for inspection and approval of forms and rebar prior to concrete placement? Who is responsible for approving adequacy of subgrade preparation for concrete slabs on grade? Who is responsible for placing and consolidation of concrete? Who will ensure that proper methods of finishing and curing are employed? What method will be used and for how long will concrete be cured? What is the minimum concrete strength required for stripping form? Will there be a formal report form for stripping forms? Will there be any in-place strength testing? Who is responsible to authorize form removal? Where will field-cured cylinders be stored and for what purpose will they be tested?

Sampling and Testing: What procedure will be followed for acceptance samples? What is the frequency for sampling and testing concrete? Will concrete be sampled as it is discharged from the truck mixer or at another location? What tests will be performed? Who will conduct the testing and who will verify that the technicians are certified? How many test cylinders will be made, how will they be cured, and at what ages will they be tested? What procedure is followed for non-conformance to specification?

Acceptance and Rejection Responsibilities for Fresh Concrete: Who has the authority to add water to the concrete on site? Who has the authority to reject concrete delivery? For what reasons can concrete be rejected? What are the tolerances for slump, air content, unit weight, and temperature? Establish re-test procedures for concrete prior to rejection.

Specimen Handling: How will cylinders be stored at the jobsite? Who is required to provide the initial curing environment for the test cylinders and how will controlled temperature and moisture be maintained? How will test cylinders be transported on weekends or non-workdays and who will arrange for access on to the site? What curing procedure is used at the testing facility? Verify that cylinders will be handled, transported and cured in accordance with ASTM C 31, or other applicable standards.

Report Distribution and Acceptance Criteria: Define the time frame for the report distribution and who will get copies of test reports. What will be on the reports and what will be the strength acceptance criteria: ACI 318, ASTM C 94 or other?

Testing of In-Place Concrete: The meeting should address what situations will require additional testing. How will the test results be evaluated, and by whom? Who incurs the expense for additional evaluations?

The items listed above are examples of some of the issues that should be discussed at a pre-construction conference. It also provides the opportunity for all involved parties to thoroughly review the specification and contract documents and if necessary make changes and improvements to them. It will also provide an understanding of responsibilities, which should be documented, for future reference.

References

1. *Ready Mixed Concrete Quality Control Checklist*, Quality Control Manual - Section 1, NRMCA, Silver Spring, MD.
2. *Concrete Pre-Construction Checklist,* Georgia Concrete & Products Association, 1st Edition.
3. *NRMCA-ASCC Checklist for the Concrete Pre-Construction Conference*, NRMCA, Silver Spring, MD.

SUGGESTED PRE-CONSTRUCTION CONFERENCE AGENDA ITEMS

- Project information and schedule
- Project participants
- Construction sequence and processes
- Base/subgrade construction and acceptance
- Site access
- Power, lighting, water
- Formwork and removal
- Placing concrete - equipment and procedures
- Vapor retarders/barriers
- Consolidation
- Finishing
- Requirements for surface finishes
- Jointing
- Curing and sealing
- Protection of concrete
- Hot and cold weather precautions
- Concrete materials and mixtures
- Specification requirements for concrete
- Jobsite adjustments
- Special materials
- Ordering and scheduling concrete delivery
- Quality control / Quality assurance
- Report distribution
- Corrective actions
- Test specimen storage, transportation and testing
- Acceptance/rejection of fresh and hardened concrete
- In-place concrete strength evaluation
- Dispute resolution and cost assignment
- Jobsite environmental management
- Jobsite safety

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CIP 33 - High Strength Concrete

WHAT is High Strength Concrete?

It is a type of high performance concrete generally with a specified compressive strength of 6,000 psi (40 MPa) or greater. The compressive strength is measured on 6 × 12 inch (150 × 300 mm) or 4 × 8 inch (100 × 200 mm) test cylinders generally at 56 or 90-days or some other specified age depending upon the application. The production of high strength concrete requires more research and more attention to quality control than conventional concrete.

WHY do We Need High Strength Concrete?

A. To put the concrete into service at much earlier age, for example <u>opening the pavement</u> at 3-days.

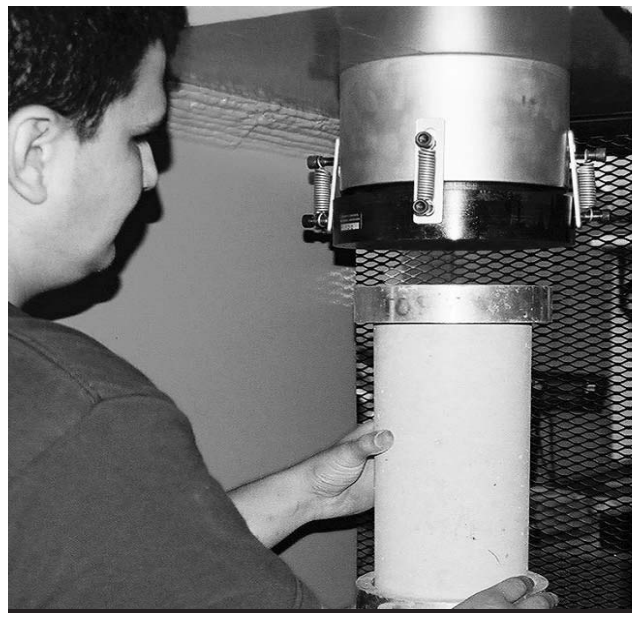
B. To build high-rise buildings by <u>reducing column</u> sizes and increasing available space.

C. To build the superstructures of long-span bridges and to enhance the durability of bridge decks.

D. To satisfy the specific needs of special applications such as durability, modulus of elasticity, and flexural strength. Some of these applications include dams, grandstand roofs, marine foundations, parking garages, and heavy duty industrial floors. (Note that high strength concrete does not guarantee durable concrete.)

HOW to Design High-Strength Concrete Mixture?

Optimum concrete mixture design results from selecting locally available materials that make the fresh concrete placeable and finishable and that ensure the strength development and other desired properties of hardened concrete as specified by the designer. Some of the basic concepts that need to be understood for high strength concrete are:



Testing High Strength Concrete

1. Aggregates should be strong and durable. They need not necessarily be hard and of high strength but need to be compatible, in terms of stiffness and strength, with the cement paste. Generally smaller maximum size coarse aggregate is used for higher strength concretes. The sand may have to be coarser than that permitted by ASTM C 33 (fineness modulus greater that 3.2) because of the high fines content from the cementitious materials.
2. High strength concrete mixtures will have a high cementitious materials content that increases the heat of hydration and possibly higher shrinkage leading to the potential for cracking. Most mixtures contain one or more supplementary cementitious materials such as fly ash (Class C or F), ground granulated blast furnace slag, silica fume, metakaolin or natural pozzolanic materials.
3. High strength concrete mixtures generally need to have a low water-cementitious materials ratio (w/cm). W/cm ratios can be in the range of 0.23 to 0.35.

These low w/cm ratios are only attainable with quite large doses of high range water reducing admixtures (or superplasticizers) conforming to Type F or G by ASTM C 494. A Type A water reducer may be used in combination.

4. The total cementitious material content will be typically around 700 lbs/yd^3 (415 kg/m^3) but not more than about 1100 lbs/yd^3 (650 kg/m^3).
5. The use of air entrainment in high strength concrete will greatly reduce the strength potential.

More attention and evaluation will be necessary if the job specification sets limits for other concrete properties such as creep, shrinkage, and modulus of elasticity. The engineer may set limits on these properties for the design of the structure. Current research may not provide the required guidance for empirical relationships of these properties from traditional tests and some of these tests are quite specialized and expensive to conduct for mixture evaluation. From theoretical considerations, lower creep and shrinkage, and high modulus of elasticity can be achieved with higher aggregate and lower paste volumes in the concrete. Using the largest size aggregate possible and medium to coarsely graded fine aggregate can attain this. Smaller maximum size aggregate such as 3/8 inch (9.5mm) can be used to produce very high compressive strength but required properties like creep, shrinkage, and modulus of elasticity may be sacrificed. If difficulty is encountered in achieving high strength, simply adding more cementitious material may not increase strength. Factors such as deleterious materials in aggregates, aggregate coatings, coarse aggregate fracture faces, shape and texture, and testing limitations may prevent higher strength from being achieved. Final concrete mixture proportions are determined by trial batches either in the laboratory or by small size field production batches. The production, transportation, placement and finishing of high-strength concrete can differ significantly from procedures used for conventional concrete. For critical projects it is highly recommended that a trial pour and evaluation be conducted and included as a pay item in the contract. Pre-bid and pre-construction meetings are very important to ensure the success of projects using high strength concrete. During construction, extra measures should be taken to protect against plastic shrinkage and thermal cracking in thicker sections. High strength concrete may need longer time before formwork is removed.

High strength concrete test cylinders should be carefully molded, cured, capped, and tested. Extra care and attention to handling of test cylinder specimens at very early age is necessary. Slower setting time of high strength concretes may be experienced. The ASTM Standards are continuously being revised to account for additional special precautions needed when testing high strength concrete. Particular attention should be paid to the type of mold, curing, type of cylinder capping material, and characteristics and load capacity of the testing machine.

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CIP 34 - Making Concrete Cylinders In the Field

WHAT are Concrete Test Cylinders?

Most commonly, the compressive strength of concrete is measured to ensure that concrete delivered to a project meets the requirements of the job specification and for quality control. For testing the compressive strength of concrete, cylindrical test specimens of size 4 ´ 8-inch (100 ´ 200-mm) or 6 ´ 12-inch (150 ´ 300-mm) are cast and stored in the field until the concrete hardens in accordance with the requirements of ASTM C 31, *Standard Practice for Making and Curing Concrete Test Specimens in the Field.*

Most specifications require that technicians certified by the ACI Field Testing Certification Grade I, or an equivalent program make test specimens in the field. When making cylinders for acceptance of concrete, the field technician must test other properties of the fresh concrete to include temperature, slump, density (unit weight) and air content. This information should accompany the set of cylinders made for a particular pour or pour location. A strength test result is always the average of at least two specimens tested at the same age. A set of 2 to 6 cylinders may be made from the same sample of concrete at a minimum for every 150 cubic yards (115 m^3) of concrete placed.

WHY Make Concrete Test Cylinders?

According to ASTM C 31, the results of *standard-cured* cylinders are used for

- Acceptance testing for specified strengths,
- Verifying mixture proportions for strength,
- Quality control by the concrete producer

It is of prime importance that the specimens are made and cured following standard procedures. Any deviation from standard procedures will result in a lower measured strength. Low strength test results due to procedures not in accordance with the standards cause undue concern, cost and delay to the project.

The strength results of *field-cured* cylinders are used for

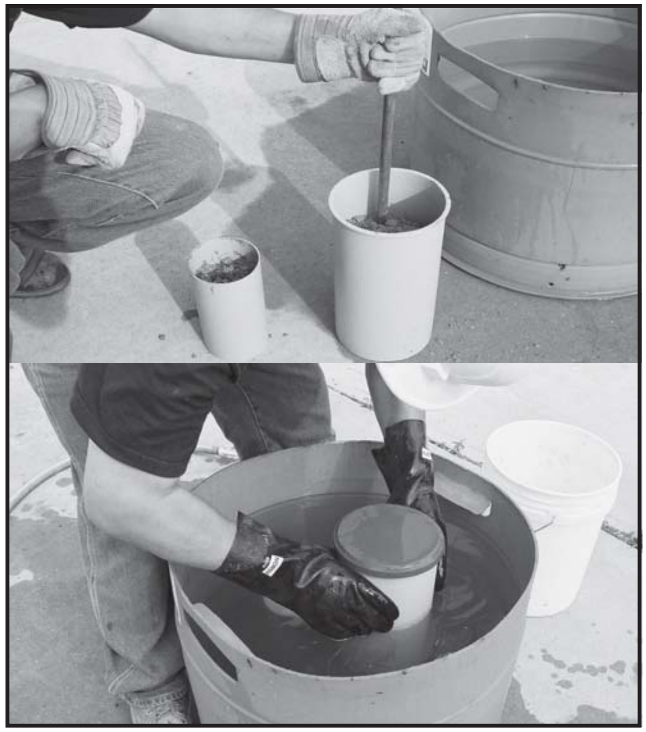
- Determining the time at which a structure is permitted to be put into service,
- Evaluating the adequacy of curing and protecting concrete in the structure, and
- Scheduling removal of forms or shoring

Curing requirements for field-cured cylinders are different from standard curing and the two should not be confused. Refer to ASTM C 31 for details on curing *field-cured* specimens.

HOW to Make & Cure Cylinders?

Equipment needed at the job site:

- Molds for casting cylinder specimens. Plastic molds are most common.
- Tamping rod with hemispherical tip - 5/8-inch (15-mm) diameter for 6 ´ 12-inch cylinders or 3/8-inch (10-mm) diameter for 4 ´ 8-inch cylinders, or a vibrator
- Rubber or rawhide mallet, 1.25 ± 0.50 lb. (0.6 ± 0.2 kg)
- Shovel, hand-held wooden float, and scoop,
- Wheelbarrow or other appropriate sample container,
- Water tank or curing box with provisions to maintain required curing environment during initial curing period.
- Safety equipment as appropriate to handle freshly mixed concrete.



Making and Curing Cylinders in the Field

Sampling concrete from a ready mixed concrete truck:

It is very important to obtain a sample of concrete that is representative of the concrete in the truck mixer. Sampling from concrete delivery units should be conducted in accordance with ASTM C 172 *Standard Practice for Sampling Freshly Mixed Concrete.* Concrete should be sampled from the middle of the load. The first or last discharge from the load will not provide a representative sample. The concrete must be sampled by diverting the chute into a wheelbarrow so that the entire discharge stream is collected. At least two portions during discharge are necessary to obtain a composite sample. The time elapsed between the first and final portion of the composite sample must not exceed 15 minutes. The minimum required size of the concrete sample is 1 cu. ft. (28 L).

Prior to Casting Cylinders:

Cover the sample with a plastic sheet to protect the concrete from evaporation, sunlight, and contamination. Move the sample to the location where the fresh concrete tests are to be conducted. The testing location should be close to where the cylinders will be stored undisturbed for the initial curing period. After the concrete is transported to the location for casting the cylinders, remix the concrete in the wheelbarrow. Begin the slump, density (unit weight), and air content tests within 5 minutes and start molding cylinders within 15 minutes after the sample was obtained.

Casting the Test Cylinders:

- Label the outside of the mold with the appropriate identification mark. Do not label the lids or tops.
- Place the cylinder molds on a level surface
- Determine the method of consolidation
  1. **For concrete with slump less than 1-inch (25-mm), concrete should be consolidated by vibration**
  2. **For concrete with slump 1-inch (25-mm) or higher, either rodding or vibrating is permitted.**
- Determine the number of layers of concrete to be placed in the mold
  1. **For concrete to be consolidated with the tamping rod, place concrete in 3 equal layers for 6 ´ 12-inch cylinders; and in 2 equal layers for 4 ´ 8-inch cylinders**
  2. **For concrete to be consolidated by vibration, fill the mold in two equal layers.**
- Place the concrete in the mold by distributing it around the inside of the mold with the scoop. Consolidate the layer by rodding 25 times evenly distributed around the layer. When using a vibrator, insert it long enough so the surface is smooth and large air pockets ceases to break through to the top. Two insertions of the vibrator are required for a 6 ´ 12-inch and one insertion is required for a 4 ´ 8-inch cylinders. Avoid over vibration.
- Tap the sides of the mold 10-15 times with the mallet after each layer in order to close any insertion holes formed either by the rod or the vibrator.
- Strike off the top with a wooden float to produce a flat, even and level surface and cover with a plastic lid or a plastic bag.

Storing and transporting test cylinders:

- Move cylinder molds with fresh concrete very carefully by supporting the bottom
- Place the cylinders on a flat surface and in a controlled environment where the temperature is maintained in the range of 60 to 80°F (16 to 27°C). When the specified strength of the concrete is greater than 6000 psi (40 MPa), the temperature range for initial curing should be maintained in the range of 68 to 78°F (20 to 26°C). Immersing cylinders, completely covered in water is an acceptable and preferred procedure that ensures more reliable strength results. Temperature in storage, such as in curing boxes, should be controlled using heating and cooling devices as necessary. The maximum and minimum temperature during initial curing should be recorded and reported.
- Protect cylinders from direct sunlight or radiant heat and from freezing temperatures in winter.
- Cylinders must be transported back to the laboratory within 48 hours of casting. Some concrete mixtures may take longer to set and these specimens may be transported at a later time. In any event cylinders should not be moved or transported until at least 8 hours after final set.

Store cylinders to prevent damage and maintain moisture during transportation. Travel time from the jobsite to the laboratory should not exceed 4 hours.

CAUTION

Fresh concrete can cause severe chemical burns to skin and eyes. Keep fresh concrete off your skin. When working with concrete use rubber work-boots, gloves, protective eyeglasses and clothing. Do not let concrete or other cement-based products soak into clothing or rub against your skin. Wash your skin promptly after contact with fresh concrete with clean water. If fresh concrete gets into your eyes, flush immediately and repeatedly with water. Consult a doctor immediately. Keep children away from all freshly mixed plastic concrete.

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   - ASTM C 39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
   - ASTM C 172, Standard Practice for Sampling Freshly Mixed Concrete
   - ASTM C 617, Standard Practice for Capping Cylindrical Concrete Specimens
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Follow These Rules to Make and Cure Standard Cured Strength Test Specimens

1. Obtain a representative concrete sample
2. Place the concrete in layers in the molds and consolidate using standard equipment and procedures
3. Finish the surface smooth and cover the cylinder with a cap or plastic bag
4. For initial curing, store cylinders in the required temperature range. Protect from direct sunlight or extreme weather.
5. Transport the cylinders to the laboratory with proper protection within 48 hours after they are made.

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Concrete in Practice

What, why & how?

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CIP 35 - Testing Compressive Strength of Concrete

WHAT is the Compression Strength of Concrete?

Concrete mixtures can be designed to provide a wide range of mechanical and durability properties to meet the design requirements of a structure. The compressive strength of concrete is the most common performance measure used by the engineer in designing buildings and other structures. The compressive strength is measured by breaking cylindrical concrete specimens in a compression-testing machine. The compressive strength is calculated from the failure load divided by the cross-sectional area resisting the load and reported in units of pound-force per square inch (psi) in US Customary units or megapascals (MPa) in SI units. Concrete compressive strength requirements can vary from 2500 psi (17 MPa) for residential concrete to 4000 psi (28 MPa) and higher in commercial structures. Higher strengths up to and exceeding 10,000 psi (70 MPa) are specified for certain applications.

WHY is Compressive Strength Determined?

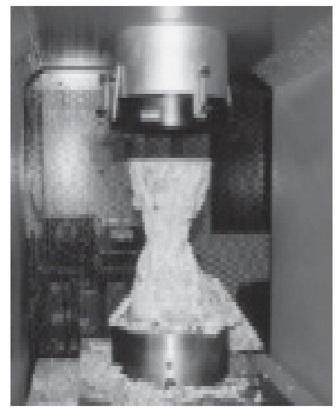
Compressive strength test results are primarily used to determine that the concrete mixture as delivered meets the requirements of the specified strength, f'_c, in the job specification.

Strength test results from cast cylinders may be used for quality control, acceptance of concrete, or for estimating the concrete strength in a structure for the purpose of scheduling construction operations such as form removal or for evaluating the adequacy of curing and protection afforded to the structure. Cylinders tested for acceptance and quality control are made and cured in accordance with procedures described for *standard-cured* specimens in ASTM C 31 *Standard Practice for Making and Curing Concrete Test Specimens in the Field.* For estimating the in-place concrete strength, ASTM C 31 provides procedures for *field-cured* specimens. Cylindrical specimens are tested in accordance with ASTM C 39, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.*

A test result is the average of at least two *standard-cured* strength specimens made from the same concrete sample and tested at the same age. In most cases strength requirements for concrete are at an age of 28 days.

Design engineers us the specified strength f'_c to design structural elements. This specified strength is incorporated in the job contract documents. The concrete mixture is designed to produce an average strength, f'_{cr}, higher than the specified strength such that the risk of not complying with the strength specification is minimized. To comply with the strength requirements of a job specification both the following acceptance criteria apply:

- The average of 3 consecutive tests should equal or exceed the specified strength, f'_c



- No single strength test should fall below f'_c by more than 500 psi (3.45 MPa); or by more than 0.10 f'_c when f'_c is more than 5000 psi (35 MPa)

It is important to understand that an individual test falling below f'_c does not necessarily constitute a failure to meet specification requirements. When the average of strength tests on a job are at the required average strength, f'_{cr}, the probability that individual strength tests will be less than the specified strength is about 10% and this is accounted for in the acceptance criteria.

When strength test results indicate that the concrete delivered fails to meet the requirements of the specification, it is important to recognize that the failure may be in the testing, not the concrete. This is especially true if the fabrication, handling, curing and testing of the cylinders are not conducted in accordance with standard procedures. *See CIP 9, Low Concrete Cylinder Strength.*

Historical strength test records are used by the concrete producer to establish the target average strength of concrete mixtures for future work.

HOW to Test the Strength of Concrete?

- Cylindrical specimens for acceptance testing should be 6 x 12 inch (150 x 300 mm) size or 4 x 8 inch (100 x 200 mm) when specified. The smaller specimens tend to be easier to make and handle in the field and the laboratory. The diameter of the cylinder used should be at least 3 times the nominal maximum size of the coarse aggregate used in the concrete.
- Recording the mass of the specimen before capping provides useful information in case of disputes.
- To provide for a uniform load distribution when testing, cylinders are capped generally with sulfur mortar (ASTM C 617) or neoprene pad caps (ASTM C 1231). Sulfur caps should be applied at least two hours and preferably one day before testing. Neoprene pad caps can be used to measure concrete strengths between 1500 and 7000 psi (10 to 50 MPa). For higher strengths upto 12,000 psi, neoprene pad caps are permitted to be used if they are qualified by companion testing with sulfur caps. Durometer hardness requirements for neoprene pads vary from 50 to 70 depending on the strength level tested. Pads should be replaced if there is excessive wear.
- Cylinders should not be allowed to dry out prior to testing.
- The cylinder diameter should be measured in two locations at right angles to each other at mid-height of the specimen and averaged to calculate the cross-sectional area. If the two measured diameters differ by more than 2%, the cylinder should not be tested.
- The ends of the specimens should not depart from perpendicularity with the cylinder axis by more than 0.5º and the ends should be plane to within 0.002 inches (0.05 mm).
- Cylinders should be centered in the compression-testing machine and loaded to complete failure. The loading rate on a hydraulic machine should be maintained in a range of 20 to 50 psi/s (0.15 to 0.35 MPa/s) during the latter half of the loading phase. The type of break should be recorded. A common break pattern is a conical fracture (*see figure*).
- The concrete strength is calculated by dividing the maximum load at failure by the average cross-sectional area. C 39 has correction factors if the length-to-diameter ratio of the cylinder is between 1.75 and 1.00, which is rare. At least two cylinders are tested at the same age and the average strength is reported as the test result to the nearest 10 psi (0.1 MPa)
- The technician carrying out the test should record the date they were received at the lab, the test date, specimen identification, cylinder diameter, test age, maximum load applied, compressive strength, type of fracture, and any defects in the cylinders or caps. If measured, the mass of the cylinders should also be noted.
- Most deviations from standard procedures for making, curing and testing concrete test specimens will result in a lower measured strength.
- The range between companion cylinders from the same set and tested at the same age should be, on average, about 2 to 3% of the average strength. If the difference between two companion cylinders exceeds 8% too often, or 9.5% for three companion cylinders, the testing procedures at the laboratory should be evaluated and rectified.
- Results of tests made by different labs on the same concrete sample should not differ by more than about 13% of the average of the two test results.
- If one or both of a set of cylinders break at strength below f'_c, evaluate the cylinders for obvious problems and *hold the tested cylinders* for later examination. Frequently the cause of a failed test can be readily seen in the cylinder, either immediately or by petrographic examination. If it is thrown away an easy opportunity to correct the problem may be lost. In some cases additional reserve cylinders are made and can be tested if one cylinder of a set broke at a lower strength.
- A 3 or 7-day test may help detect potential problems with concrete quality or testing procedures at the lab but is not a basis for rejecting concrete, with a requirement for 28-day or other age strength.
- ASTM C 1077 requires that laboratory technicians involved in testing concrete must be certified.
- Reports of compressive strength tests provide valuable information to the project team for the current and future projects. The reports should be forwarded to the concrete producer, contractor and the owner's representative as expeditiously as possible.

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2003

Concrete in Practice

What, why & how?

NRMCA

CIP 36 - Structural Lightweight Concrete

WHAT is Structural Lightweight Concrete?

Structural lightweight concrete has an in-place density (unit weight) on the order of 90 to 115 lb/ ft^3 (1440 to 1840 kg/m^3) compared to normalweight concrete with a density in the range of 140 to 150 lb/ ft^3 (2240 to 2400 kg/m^3). For structural applications the concrete strength should be greater than 2500 psi (17.0 MPa). The concrete mixture is made with a lightweight coarse aggregate. In some cases a portion or the entire fine aggregate may be a lightweight product. Lightweight aggregates used in structural lightweight concrete are typically expanded shale, clay or slate materials that have been fired in a rotary kiln to develop a porous structure. Other products such as air-cooled blast furnace slag are also used. There are other classes of non-structural lightweight concretes with lower density made with other aggregate materials and higher air voids in the cement paste matrix, such as in cellular concrete. These are typically used for their insulation properties. This CIP focuses on structural lightweight concrete.

WHY Use Structural Lightweight Concrete?

The primary use of structural lightweight concrete is to reduce the dead load of a concrete structure, which then allows the structural designer to reduce the size of columns, footings and other load bearing elements. Structural lightweight concrete mixtures can be designed to achieve similar strengths as normalweight concrete. The same is true for other mechanical and durability performance requirements. Structural lightweight concrete provides a more efficient strength-to-weight ratio in structural elements. In most cases, the marginally higher cost of the lightweight concrete is offset by size reduction of structural elements, less reinforcing steel and reduced volume of concrete, resulting in lower overall cost.

In buildings, structural lightweight concrete provides a higher fire-rated concrete structure. Structural lightweight concrete also benefits from energy conservation considerations as it provides higher R-values of wall elements for improved insulation properties. The porosity of lightweight aggregate provides a source of water for internal curing of the concrete that provides continued enhancement of concrete strength and durability. This does not preclude the need for external curing.

Sprinkling Aggregate in a Stockpile

Structural lightweight concrete has been used for bridge decks, piers and beams, slabs and wall elements in steel and concrete frame buildings, parking structures, tilt-up walls, topping slabs and composite slabs on metal deck.

HOW is Structural Lightweight Concrete Used?

Lightweight concrete can be manufactured with a combination of fine and coarse lightweight aggregate or coarse lightweight aggregate and normalweight fine aggregate. Complete replacement of normalweight fine aggregate with a lightweight aggregate will decrease the concrete density by approximately 10 lb/ft^3 (160 kg/m^3).

Designers recognize that structural lightweight concrete will not typically serve in an oven-dry environment. Therefore, structural design generally relies on an *equilibrium* density (sometimes referred to as *air-dry* density); the condition in which some moisture is retained within the lightweight concrete. Equilibrium density is a standardized value intended to represent the approximate density of the in-place concrete when it is in service. Project specifications should indicate the required equilibrium density of the lightweight concrete. Equilibrium density is defined in ASTM C 567, and can be calculated from the concrete mixture proportions. Field acceptance is based on measured density of fresh concrete in accordance with ASTM C 138. Equilibrium density will be approximately 3 to 8 lb/ ft^3 (50 to 130 kg/m^3) less than the fresh density and a correlation should be agreed upon prior to delivery of concrete. The tolerance for acceptance on fresh density is typically ±3 lb/ ft^3 (±50 kg/m^3) from the target value.

Lightweight aggregates must comply with the requirements of ASTM Specification C 330. Due to the cellular nature of lightweight aggregate particles absorption typically is in the range of 5% to 20% by weight of dry aggregate. Lightweight aggregates generally require wetting prior to use to achieve a high degree of saturation. Some concrete producers may not have the capability of prewetting lightweight aggregates in cold weather if temperature controlled storage is not available. Some lightweight aggregate suppliers furnish vacuum saturated aggregate.

With the exception of bridges and marine structures, specifications for structural lightweight concrete do not typically have a requirement for maximum water-to-cementitious materials (w/cm) ratio. The w/cm ratio of structural lightweight concrete cannot be precisely determined because of the difficulty in determining the absorption of lightweight aggregate.

Air content of structural lightweight concrete must be closely monitored and controlled to ensure that the density requirements are being achieved. Testing for air content must be according to the volumetric method, ASTM C 173, or calculated using the gravimetric method described in ASTM C 138. Virtually all lightweight concrete is air-entrained.

Finishing lightweight concrete requires proper attention to detail. Excessive amounts of water or excessive slump will cause the lightweight aggregate to segregate from the mortar. Bullfloating will generally provide an adequate finish. If the surface for an interior floor is to receive a hard troweled finish, use precautions to minimize the formation of blisters or delaminations. See CIPs 13 and 20 for discussions on blisters and delaminations, respectively.

Due to the inherent higher total moisture content of lightweight concrete it typically takes a longer time than normalweight concrete to dry to levels that might be considered adequate for application of floor covering materials.

The splitting tensile strength of lightweight concrete is used in structural design criteria. The design engineer may request the information for a particular source of lightweight aggregate prior to the design. The splitting tensile strength corresponding to the specified compressive strength is determined in laboratory evaluations. Splitting tensile strength testing is not used as a basis for field acceptance of concrete.

Ensure that the requirements of the designer relative to fire resistance or insulation properties of lightweight concrete building elements are in conformance with applicable industry standards. For a successful project, information is available from the supplier of lightweight aggregate and the ready mixed concrete producer. With proper planning, structural lightweight concrete can provide an economical solution to many engineering applications.

References

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Guidelines For Pumping

Lightweight concrete placements frequently employ pumps and this can be done successfully when a few precautions are considered prior to the actual placement.

1. Aggregate should be adequately pre-soaked as pressure during pumping will drive water into the aggregate pores and cause slump loss that may result in plugging of the pump line and difficulties in placement and finishing.
2. Pump lines should be as large as possible, preferably 5-inch (125-mm) diameter, with a minimum number of elbows, reducers or rubber hose sections.
3. The lowest practical pressure should be used.
4. Pump location should be such that vertical fall of the concrete is minimized.
5. Adjustments to mixture characteristics, such as slump, aggregate content and air content may be necessary to ensure adequate pumpability for the job conditions.
6. Decide on where concrete samples for acceptance tests will be taken and what implications this would have on the concrete mixture proportions and properties as delivered to the jobsite.

Concrete in Practice

What, why & how?

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CIP 37 - Self Consolidating Concrete (SCC)

WHAT is Self Consolidating Concrete (SCC)?

Self consolidating concrete (SCC), also known as self compacting concrete, is a highly flowable, non-segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement without any mechanical consolidation. The flowability of SCC is measured in terms of spread when using a modified version of the slump test (ASTM C 143). The spread (slump flow) of SCC typically ranges from 18 to 32 inches (455 to 810 mm) depending on the requirements for the project. The viscosity, as visually observed by the rate at which concrete spreads, is an important characteristic of plastic SCC and can be controlled when designing the mix to suit the type of application being constructed.

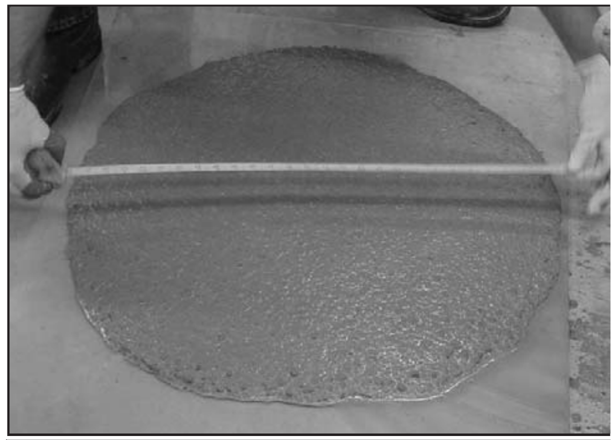

Figure 1 SCC with a slump flow of 29” (735 mm) as tested by the slump flow test

WHY is SCC Used?

Some of the advantages of using SCC are:

1. Can be placed at a faster rate with no mechanical vibration and less screeding, resulting in savings in placement costs.
2. Improved and more uniform architectural surface finish with little to no remedial surface work.
3. Ease of filling restricted sections and hard-to-reach areas. Opportunities to create structural and architectural shapes and surface finishes not achievable with conventional concrete.
4. Improved consolidation around reinforcement and bond with reinforcement
5. Improved pumpability.
6. Improved uniformity of in-place concrete by eliminating variable operator-related effort of consolidation.
7. Labor savings.
8. Shorter construction periods and resulting cost savings.
9. Quicker concrete truck turn-around times enabling the producer to service the project more efficiently.
10. Reduction or elimination of vibrator noise potentially increasing construction hours in urban areas.
11. Minimizes movement of ready mixed trucks and pumps during placement.
12. Increased jobsite safety by eliminating the need for consolidation.

HOW is SCC Achieved?

Two important properties specific to SCC in its plastic state are its *flowability* and *stability*. The high flowability of SCC is generally attained by using high-range-water-reducing (HRWR) admixtures and not by adding extra mixing water. The stability or resistance to segregation of the plastic concrete mixture is attained by increasing the total quantity of fines in the concrete and/or by using admixtures that modify the viscosity of the mixture. Increased fines contents can be achieved by increasing the content of cementititious materials or by incorporating mineral fines. Admixtures that affect the viscosity of the mixture are especially helpful when grading of available aggregate sources cannot be optimized for cohesive mixtures or with large source variations. A well distributed aggregate grading helps achieve SCC at reduced cementitious materials content and/or reduced admixture dosage. While SCC mixtures have been successfully produced with 1½ inch (38 mm) aggregate, it is easier to design and control with smaller size aggregate. Control of aggregate moisture content is also critical to producing a good mixture. SCC mixtures typically have a higher paste volume, less coarse aggregate and higher sand-coarse aggregate ratio than typical concrete mixtures.

Retention of flowability of SCC at the point of discharge at the jobsite is an important issue. Hot weather, long haul distances and delays on the jobsite can result in the reduction of flowability whereby the benefits of using SCC are reduced. Job site water addition to SCC may not always yield the expected increase in flowability and could cause stability problems.

Full capacity mixer truck loads may not be feasible with SCCs of very high flowability due to potential spillage. In such situations it is prudent to transport SCC at a lower flowability and adjust the mixture with HRWR admixtures at the job site. Care should be taken to maintain the stability of the mixture and minimize blocking during pumping and placement of SCC through restricted spaces. Formwork may have to be designed to withstand fluid concrete pressure and conservatively should be designed for full head pressure. SCC may have to be placed in lifts in taller elements. Once the concrete is in place it should not display segregation or bleeding/settlement.

SCC mixtures can be designed to provide the required hardened concrete properties for an application, similar to regular concrete. If the SCC mixture is designed to have a higher paste content or fines compared to conventional concrete, an increase in shrinkage may occur.

HOW to Test SCC?

Several test procedures have been successfully employed to measure the plastic properties of SCC. The slump flow test (see Figure 1), using the traditional slump cone, is the most common field test and is in the process of being standardized by ASTM. The slump cone is completely filled without consolidation, the cone lifted and the spread of the concrete is measured. The spread can range from 18 to 32 inches (455 to 810 mm). The resistance to segregation is observed through a visual stability index (VSI). The VSI is established based on whether bleed water is observed at the leading edge of the spreading concrete or if aggregates pile at the center. VSI values range from 0 for "highly stable" to 3 for unacceptable stability.

During the slump flow test the viscosity of the SCC mixture can be estimated by measuring the time taken for the concrete to reach a spread diameter of 20 inches (500 mm) from the moment the slump cone is lifted up. This is called the T_{20} (T_{50}) measurement and typically varies between 2 and 10 seconds for SCC. A higher T_{20} (T_{50}) value indicates a more viscous mix which is more appropriate for concrete in applications with congested reinforcement or in deep sections. A lower T_{20} (T_{50}) value may be appropriate for concrete that has to travel long horizontal distances without much obstruction.

The U-Box and L-Box tests are used for product development or prequalification and involve filling concrete on one side of the box and then opening a gate to allow the concrete to flow through the opening containing rebar. The J-ring test is a variation to the slump flow, where a simulated rebar cage is placed around the slump cone and the ability of the SCC mix to spread past the cage without segregation is evaluated. The U-box, L-box and J-ring tests measure the *passing ability* of concrete in congested reinforcement. Another test being standardized is a column test which measures the coarse aggregate content of concrete at different heights in a placed columnar specimen as an indication of stability or resistance to segregation.

HOW to Order or Specify SCC?

When ordering and/or specifying SCC, consideration must be given to the end use of the concrete. Ready mixed concrete producers will generally have developed mixture proportions based on performance and applications. The required spread (slump flow) is based on the type of construction, selected placement method, complexity of the formwork shape and the configuration of the reinforcement. ACI Committee 237 is completing a guidance document that will provide guidelines to select the appropriate slump flow for various conditions. The lowest slump flow required for the job conditions must be specified. This will ensure SCC can be attained easily with required stability and at the lowest possible cost. The hardened concrete properties should be specified by the design professional based on structural and service requirements of the structure. For the most part, hardened concrete properties of SCC are similar to conventional concrete mixtures. Based on the requirements of each project, SCC concrete designs can be submitted by the producer only after specification provisions regarding the performance of the concrete in its plastic and hardened state are clearly defined.

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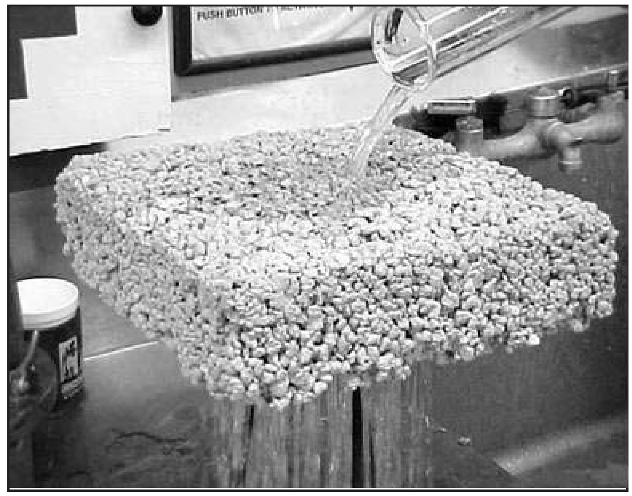
2004

Concrete in Practice
What, why & how?
NRMCA

CIP 38 - Pervious Concrete



WHAT is Pervious Concrete?

Pervious concrete is a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and other sources to pass through it, thereby reducing the runoff from a site and recharging ground water levels. The high porosity is attained by a highly interconnected void content. Typically pervious concrete has little to no fine aggregate and has just enough cementitious paste to coat the coarse aggregate particles while preserving the interconnectivity of the voids. Pervious concrete is traditionally used in parking areas, areas with light traffic, pedestrian walkways, and greenhouses. It is an important application for sustainable construction.

WHY Use Pervious Concrete?

The proper utilization of pervious concrete is a recognized Best Management Practice by the U.S. Environmental Protection Agency (EPA) for providing first-flush pollution control and storm water management. As regulations further limit storm water runoff, it is becoming more expensive for property owners to develop real estate, due to the size and expense of the necessary drainage systems. Pervious concrete reduces the runoff from paved areas, which reduces the need for separate storm water retention ponds and allows the use of smaller capacity storm sewers. This allows property owners to develop a larger area of available property at a lower cost. Pervious concrete also naturally filters storm water and can reduce pollutant loads entering into streams, ponds and rivers. Pervious concrete functions like a storm water retention basin and allows the storm water to infiltrate the soil over a large area, thus facilitating recharge of precious groundwater supplies locally. All of these benefits lead to more effective land use.

Pervious concrete can also reduce the impact of development on trees. A pervious concrete pavement allows the transfer of both water and air to root systems allowing trees to flourish even in highly developed areas.

HOW to Create a Pervious Concrete Pavement?

An experienced installer is vital to the success of pervious concrete pavements. As with any concrete pavement, proper subgrade preparation is important. The subgrade should be properly compacted to provide a uniform and stable surface. When pervious pavement is placed directly on sandy or gravelly soils it is recommended to compact the subgrade to 92 to 96% of the maximum density (ASTM D 1557). With silty or clayey soils, the level of compaction will depend on the specifics of the pavement design and a layer of open graded stone may have to be placed over the soil. Engineering fabrics are often used to separate fine grained soils from the stone layer. Care must be taken not to over-compact soil with swelling potential. Moisten the subgrade prior to concrete placement, and wheel ruts from the construction traffic should be raked and re-compacted. Moistening the subgrade prevents pervious concrete from setting and drying too quickly.

Typically pervious concrete has a water to cementitious materials (w/cm) ratio of 0.35 to 0.45 with a void content of 15 to 25%. The mixture is composed of cementitious materials, coarse aggregate and water with little to no fine aggregates. Addition of a small amount of fine aggregate will generally reduce the void content and increase the strength, which may be desirable in certain situations. This material is sensitive to changes in water content, so field adjustment of the fresh mixture is usually necessary. The correct quantity of water in the concrete is critical. Too much water will cause segregation, and too little water will lead to balling in the mixer and very slow mixer unloading. Too low a water content can also hinder adequate curing of the concrete and lead to a premature raveling surface failure. A properly proportioned mixture gives the mixture a wet-metallic appearance or sheen.

A pervious concrete pavement may be placed with either fixed forms or slip-form paver. The most common approach to placing pervious concrete is in forms on grade that have a riser strip on the top of each form such that the strike off device is actually 3/8-1/2 in. (9 to 12 mm) above final pavement elevation. Strike off may be by vibratory or manual screeds, though vibratory screens are preferable. After striking off the concrete, the riser strips are removed and the concrete compacted by a manually operated roller that bridges the forms. Rolling consolidates the fresh concrete to provide strong bond between the paste and aggregate, and creates a smoother riding surface. Excessive pressure when rolling should be avoided as it may cause the voids to collapse. Rolling should be performed immediately after strike off.

Jointing pervious concrete pavement follows the same rules as for concrete slabs on grade, with a few exceptions. With significantly less water in the fresh concrete, shrinkage of the hardened material is reduced significantly, thus, joint spacings may be wider. The rules of jointing geometry, however, remain the same (See CIP 6). Joints in pervious concrete are tooled with a rolling jointing tool. This allows joints to be cut in a short time, and allows curing to continue uninterrupted.

Proper curing is essential to the structural integrity of a pervious concrete pavement. Curing ensures sufficient hydration of the cement paste to provide the necessary strength in the pavement section to prevent raveling. Curing should begin within 20 minutes of concrete placement and continue through 7 days. Plastic sheeting is typically used to cure pervious concrete pavements.

HOW to Test and Inspect Pervious Concrete Pavement?

Pervious concrete can be designed to attain a compressive strength ranging from 400 psi to 4000 psi (2.8 to 28 MPa) though strengths of 600 psi to 1500 psi (2.8 to 10 MPa) are more common. Pervious concrete, however, is not specified or accepted based on strength. More important to the success of a pervious pavement is the void content. Acceptance is typically based on the density (unit weight) of the in-place pavement. An acceptable tolerance is plus or minus 5 lb/cu.ft. (80 kg/m^3) of the design density. This should be verified through field testing. The fresh density (unit weight) of pervious concrete is measured using the jigging method described in ASTM C 29. Slump and air content tests are not applicable to pervious concrete. If the pervious concrete pavement is an element of the storm water management plan, the designer should ensure that it is functioning properly through visual observation of its drainage characteristics prior to opening of the facility. Questions have been raised about the freeze thaw durability of pervious concrete. Even though most of the experience with pervious concrete has been in warmer climates recently there have been several pervious concrete projects in colder climates. Pervious concrete in freeze thaw environment must not become fully saturated. Saturation of installed pervious concrete pavement can be prevented by placing the pervious concrete on a thick layer of 8 to 24 inches (200 to 600 mm) of open graded stone base. Limited laboratory testing has shown that entrained air may improve the freeze thaw durability even when the pervious concrete is in a fully saturated condition. However, the entrained air content cannot be verified by any standard ASTM test procedure.

EPA recommends that pervious concrete pavement be cleaned regularly to prevent clogging. Cleaning can be accomplished through vacuum sweeping or high pressure washing. Even though pervious concrete and the underlying soil provide excellent filtration capabilities, all the contaminants may not be removed. In critical situations to preserve the quality of ground water, storm water testing is recommended.

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