NRMCA

What, Why & How?

Dusting Concrete Surfaces

CONCRETE IN PRACTICE CIP 1

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 concrete temperatures 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 the environment, especially freezing.

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What, Why & How?
Scaling Concrete Surfaces

CONCRETE IN PRACTICE — CIP 2

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)

WHY Do Concrete Surfaces Scale?

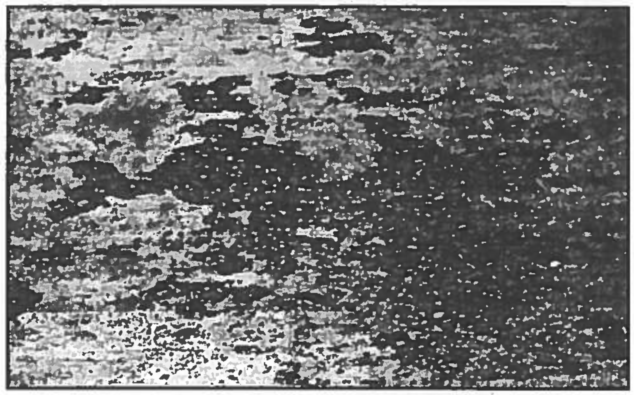
Concrete slabs exposed to freezing and thawing in the presence of moisture and/or deicing salts are susceptible to scaling. Most scaling is caused by:

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.



Scaling concrete surface

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 Repair 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.
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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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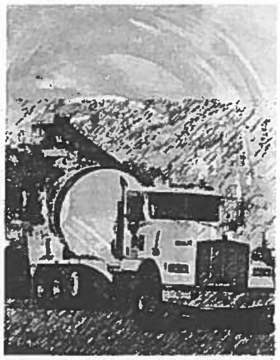

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What, Why & How?
Crazing Concrete Surfaces

CONCRETE IN PRACTICE — CIP 3

WHAT is Crazing?

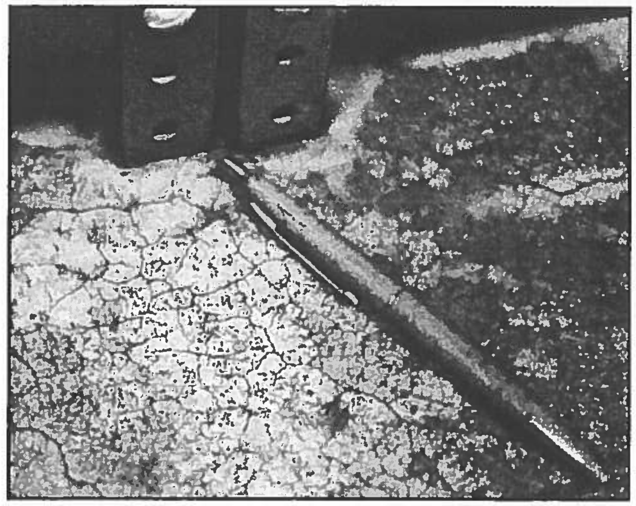
Crazing is the development of a network of fine random cracks or fissures on the surface of concrete or mortar caused by shrinkage of the surface layer. These cracks are rarely more than 1/8 inch [3 mm] deep and are more noticeable on steel-troweled surfaces. The irregular hexagonal areas enclosed by 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.

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.



Crazing Concrete Surface (Dampened)

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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What, Why & How?
Cracking Concrete Surfaces

CONCRETE IN PRACTICE — CIP 4

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)

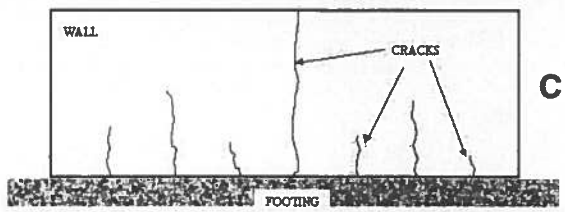
Figure D: Cracks due to lack of an isolation joint (See CIP 6)

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.



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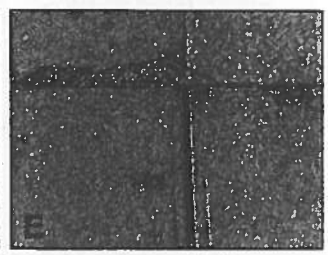

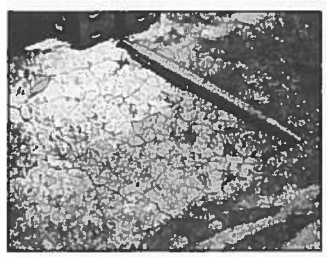

WHY Do Concrete Surfaces Crack?

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 possible to produce completely crack-free concrete. However, cracking can be reduced and controlled if the following basic 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.
3. *Concrete Slab Surface Defects: Causes, Prevention, Repair*, IS177, Portland Cement Association, Skokie, IL.
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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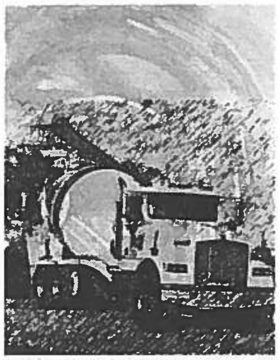

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What, Why & How?
Plastic Shrinkage Cracking

CONCRETE IN PRACTICE — CIP 5

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 Cracks

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 c ncrete 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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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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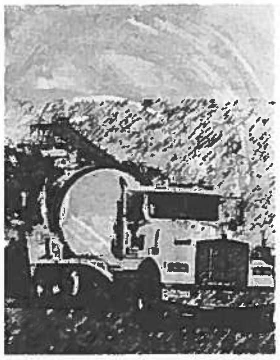


NRMCA

What, Why & How? Joints in Concrete Slabs on Grade

CONCRETE IN PRACTICE — CIP 6

WHAT are Joints?

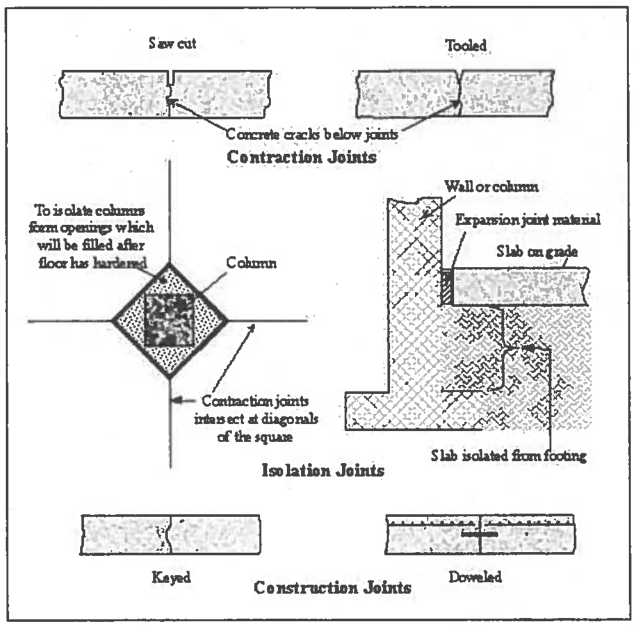
Concrete expands and shrinks with changes in moisture and temperature. The overall tendency is to shrink and this can cause cracking at an early age. Irregular cracks are unsightly and difficult to maintain but generally do not affect the integrity of concrete. Joints are simply pre-planned cracks. Joints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

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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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What, Why & How?

Cracks in Concrete Basement Walls

CONCRETE IN PRACTICE — CIP 7

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.

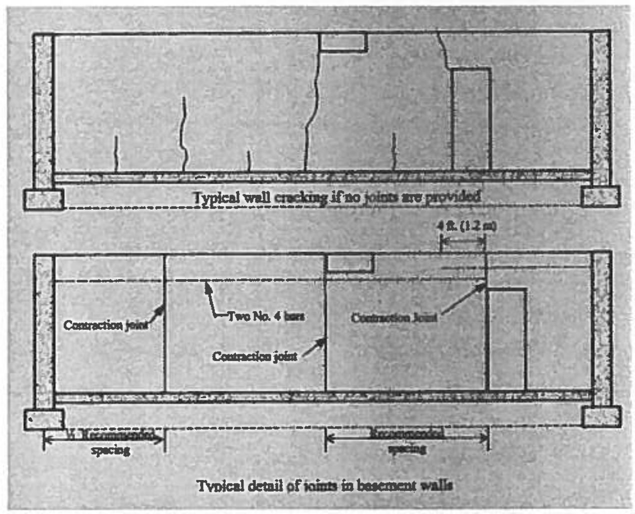
WHY do Basement Cracks Occur?

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.

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.

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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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What, Why & How?

Discrepancies in Yield

CONCRETE IN PRACTICE

CIP 8

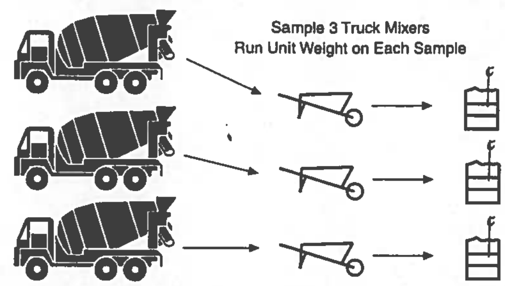
WHAT is Concrete Yield?

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.

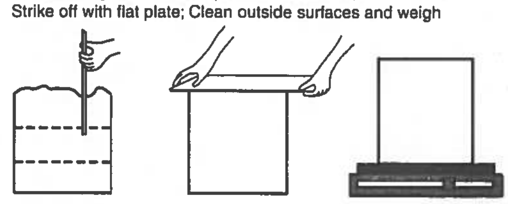
The basis for calculating the volume is described in the ASTM C 94, *Specification for Ready Mixed Concrete*. The volume of freshly mixed and unhardened concrete in a given batch is determined by dividing the total weight of the materials by the average unit weight or density of the concrete determined 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



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

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

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

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

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 cleane 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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What, Why & How?
Low Concrete Cylinder Strength

CONCRETE IN PRACTICE — CIP 9

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.

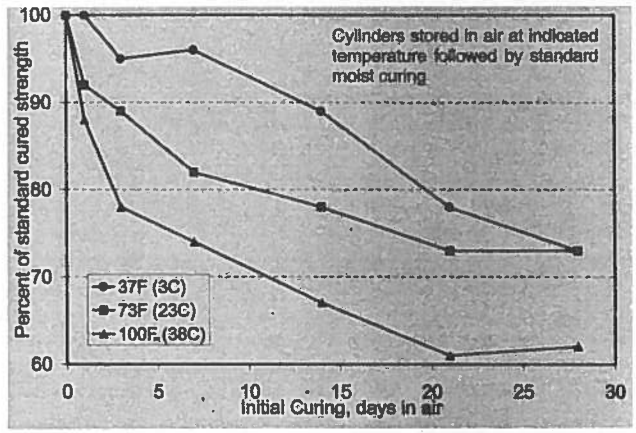
See the example in the table. If an average of three consecutive *tests* in sequence falls below the specified strength, steps must be taken to increase the strength of the concrete. If a single *test* falls more than 500 psi (3.5 MPa) below the specified strength, an investigation should be made to 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)

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.

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 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.

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CIP 100/9/0060/10.0/DMSC

NRMCA

What, Why & How?

Strength of In-Place Concrete

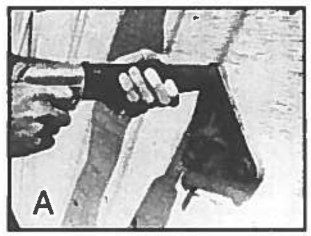
CONCRETE IN PRACTICE — CIP 10

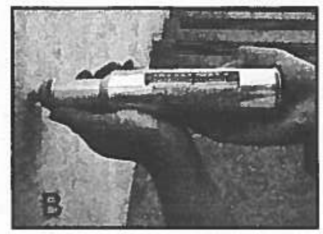
WHAT is the Strength of In-Place Concrete?

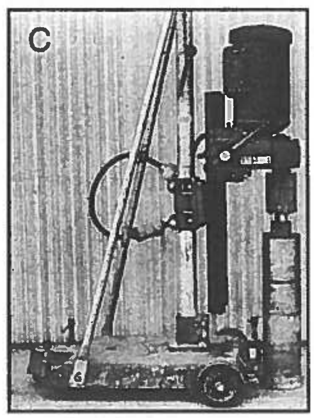
Concrete structures are designed to carry dead and live loads during construction and in service. Samples of concrete are obtained during construction and standard ASTM procedures are used to measure the potential strength of the concrete as delivered. Cylinders are molded and cured at 60 to 80°F (17 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.







A - Penetration Resistance Test (ASTM C 803)

B - Rebound Test (ASTM C 805)

C - Core Test (ASTM C 42)

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.

HOW to Investigate In-Place Strength

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 3½ 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 1½ times the diameter (L/D ratio);
d. Trim to remove steel provided the minimum 1½ 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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What, Why & How?
Curing In-Place Concrete

CONCRETE IN PRACTICE — CIP 11

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).

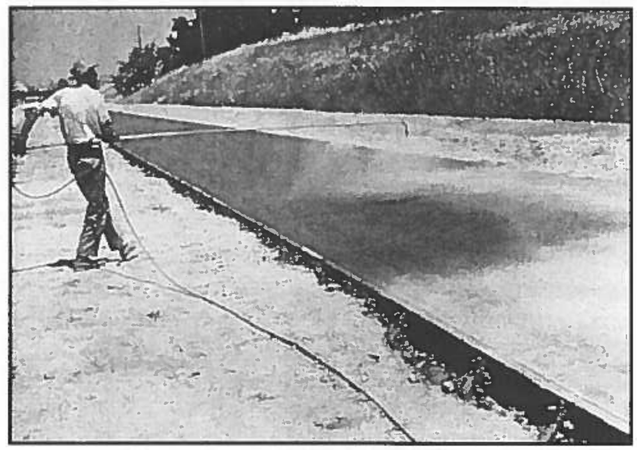
WHY Cure?

Several important reasons are:

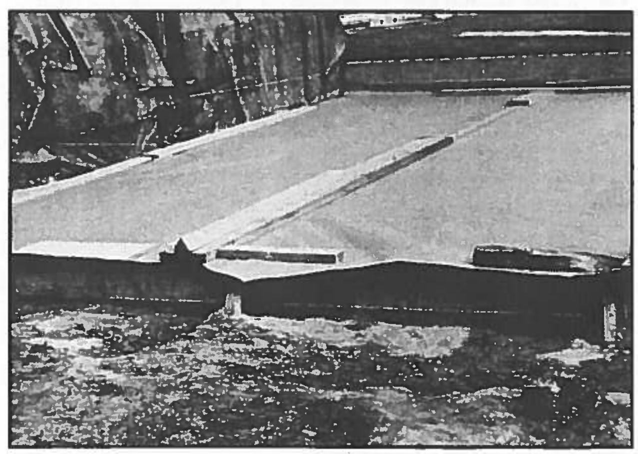
a. **Predictable strength gain.** Laboratory tests show that concrete in a dry environment can lose as much as 50 percent of its potential strength compared to similar concrete that is moist cured. Concrete placed under high temperature conditions will gain early strength quickly but later strengths 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.

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.

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.

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.

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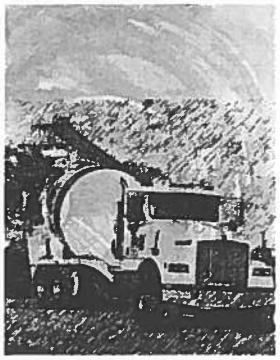


NRMCA

What, Why & How?
Hot Weather Concreting

CONCRETE IN PRACTICE — CIP 12

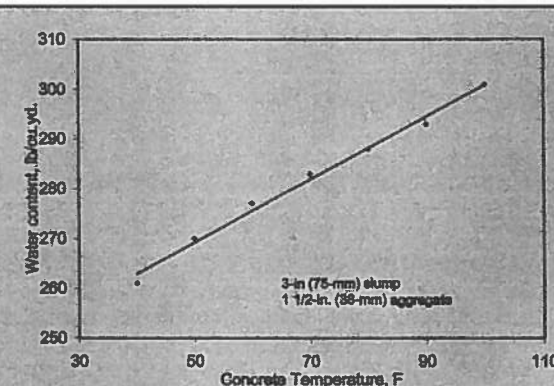
WHAT is Hot Weather?

Hot weather may be defined as any period of high temperature in which special precautions need to be taken to ensure proper handling, placing, finishing and curing of concrete. Hot weather problems are most frequently encountered in the summer, but the associated climatic factors of high winds, low relative humidity and solar radiation can occur at any time, especially in arid or tropical climates. Hot weather conditions can produce a rapid rate of evaporation of moisture from the surface of the concrete and accelerated setting time, among other problems. Generally, high relative humidity tends to reduce the effects of high temperature.

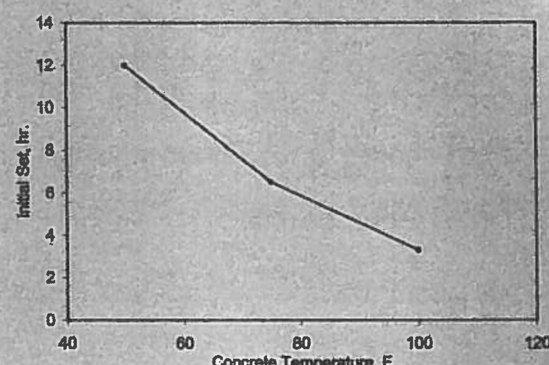
WHY Consider Hot Weather?

It is important that hot weather be taken into account when planning concrete projects because of the potential effects on fresh and recently placed concrete. High temperatures alone cause increased water demand, which, in turn, will raise the water-cement ratio and result in lower potential strength. Higher temperatures tend to accelerate slump loss and can cause loss of entrained air. Temperature also has a major effect on the setting time of concrete: concrete placed under high temperatures will set quicker and can, therefore, require more rapid finishing. Concrete that is cured at high temperatures at an early age will not be as strong at 28 days as the same concrete cured at temperatures in the range of 70°F (20°C).

High temperatures, high wind velocity, and low relative humidity can affect fresh concrete in two important ways: the high rate of evaporation may induce early plastic shrinkage or drying shrinkage cracking, and the evaporation rate can remove surface water necessary for hydration unless proper curing methods are employed. Thermal cracking may result from rapid drops in the temperature of the concrete, such as when concrete stabs or walls are placed on a hot day followed by a cool night. High temperature also accelerates cement hydration and contributes to the potential for thermal cracking in massive concrete structures.



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



Effect of temperature on concrete setting time (Ref 1)

HOW to Concrete in Hot Weather

The key to successful hot weather concreting is:

1. recognition of the factors that affect concrete; and
2. planning to minimize their effects.

Use proven local recommendations for adjusting concrete proportions, such as the use of water reducing and set retarding admixtures. Modifying the mixture to reduce the heat generated by cement hydration, such as the use of an ASTM Type II moderate heat cement and the use of pozzolans and slag can reduce potential problems with high concrete temperature. Advance timing and scheduling to avoid delays in delivery, placing and finishing is essential. Trucks should be able to discharge immediately and adequate personnel should be available to place and handle the concrete. When possible, deliveries should be scheduled to avoid the hottest part of the day. Limits on maximum concrete temperature may be waived by the purchaser if the concrete consistency is adequate for the placement and excessive water addition is not required.

In the case of extreme temperature conditions or with mass concrete, the concrete temperature can be lowered by using chilled water or ice as part of the mixing water. The ready mixed concrete producer uses other measures, such as sprinkling and shading the aggregate prior to mixing, to help lower the temperature of the concrete.

If low humidity and high winds are predicted, windbreaks, sunscreens, mist fogging, or evaporation retardants may be needed to avoid plastic shrinkage cracking in slabs.

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Follow These Rules for Hot Weather Concrete

1. Modify concrete mix designs as appropriate. Retarders, moderate heat of hydration cement, pozzolanic materials, slag, or other proven local solutions may be used. Reduce the cement content of the mixture as much as possible, while ensuring the concrete strength will be attained.
2. Have adequate manpower to quickly place, finish and cure the concrete.
3. Limit the addition of water at the job site—add water only on arrival at the job site to adjust the slump. Water addition should not exceed about 2 to 2½ gallons per cubic yard (10 to 12 L/m³). Adding water to concrete that is more than 1½ hours old should be avoided.
4. Slabs on grade should not be placed directly on polyethylene sheeting or other vapor retarders. Cover the vapor retarder with a minimum 4-inch (100 mm) layer of compactible, easy-to-trim, granular fill material.
5. On dry and/or hot days, when conditions are conducive for plastic shrinkage cracking, dampen the subgrade, forms and reinforcement prior to placing concrete, but do not allow excessive water to pond.
6. Begin final finishing operations as soon as the waater sheen has left the surface; start curing as soon as finishing is completed. Continue curing for at least 3 days; cover the concrete with wet burlap and plastic sheeting to prevent evaporation or use a liquid membrane curing compound, or cure slabs with water (See CIP 11). Using white pigmented membrane curing compounds will help by indicating proper coverage and reflecting heat away from the concrete surface.
7. Protect test cylinders at the jobsite by shading and preventing evaporation. Field curing boxes with ice or refrigeration may be used to ensure maintaining the required 60 to 80°F (17 to 27°C) for initial curing of cylinders. (See CIP 9)
8. Do not use accelerators unless it is common practice to avoid plastic shrinkage cracking and expedite finishing operations.

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What, Why & How?
Concrete Blisters

CONCRETE IN PRACTICE CIP 13

WHAT are Blisters?

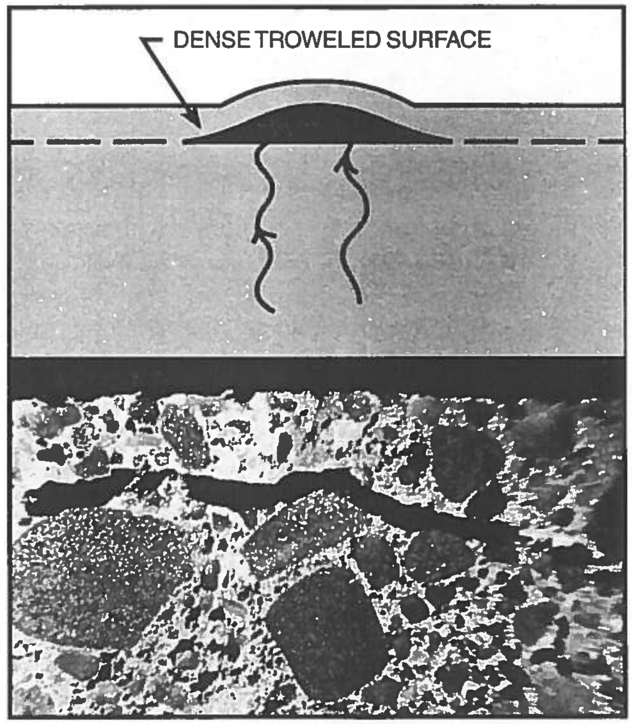
Blisters are hollow, low-profile bumps on the concrete surface, typically from the size of a dime up to about 1 inch (25 mm), but occasionally even 2 or 3 inches (50-75 mm) in diameter. A dense troweled skin of mortar about ⅛ in. (3 mm) thick covers an underlying void that moves around under the surface during troweling. Blisters may occur shortly after the completion of finishing operations. 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:

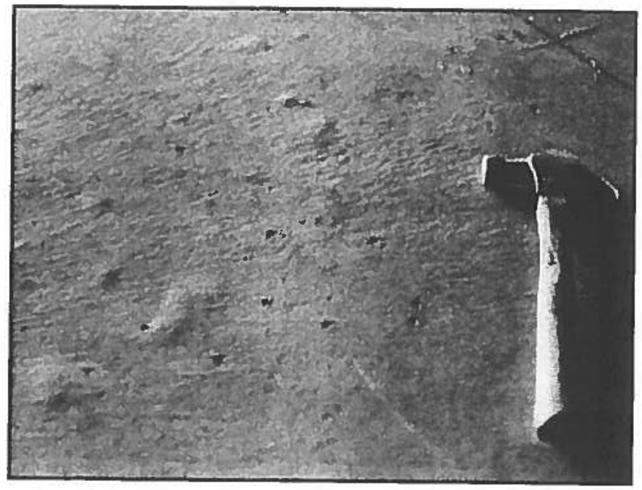
1. Insufficient or excessive vibration is employed. Insufficient vibration prevents the entrapped air from being released and excessive use of vibrating screeds works up a thick mortar layer on the surface.
2. An improper tool is used for floating the surface or it is used improperly. The surface should 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 the 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



Concrete Blister

fines in the sand. These mixtures also bleed less 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 operations 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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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 set-accelerated concrete to promote even setting throughout the depth of the slab in cooler weather
4. Do not place slabs directly on polyethylene vapor retarder sheeting.
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.

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What, Why & How?
Finishing Concrete Flatwork

CONCRETE IN PRACTICE | CIP 14

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.

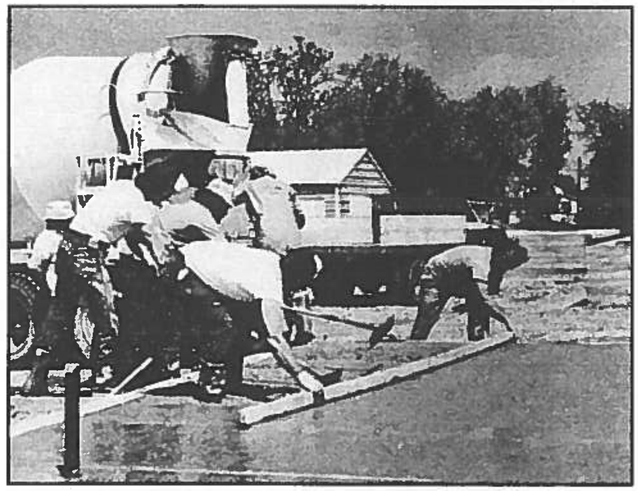
HOW to Place Concrete

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 (75 mm). 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 1/4 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.

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5. *Residential Concrete*, National Association of Home Builders, Washington, D.C.
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Follow these Rules to Place and 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.

Technical information prepared by

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NRMCA

What, Why & How? Chemical Admixtures for Concrete

CONCRETE IN PRACTICE CIP 15

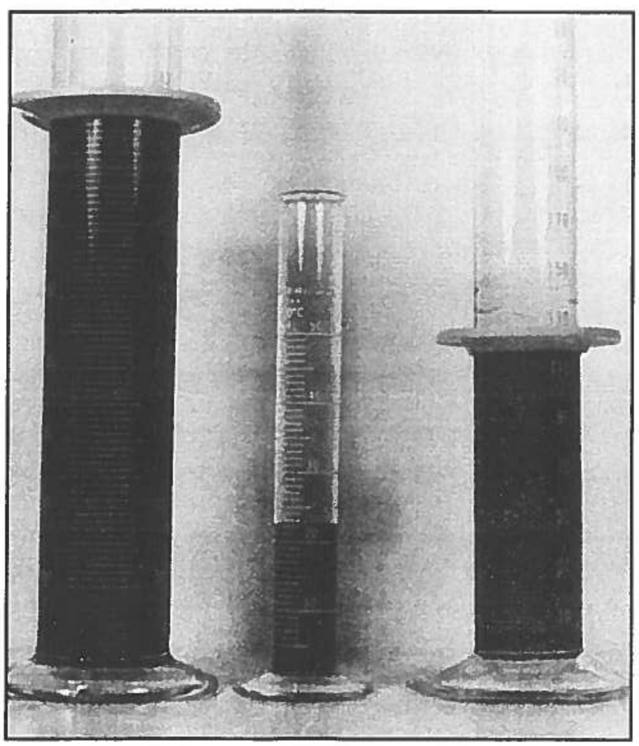
WHAT are Admixtures?

Admixtures are natural or manufactured chemicals 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 the 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-reducers 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 requirements 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 time 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 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 the 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 from 12 to 25%. HRWR are therefore used to increase strength and reduce permeability of concrete by reducing the water content in the mixture; or to 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 added 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 ½)	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.aci-int.org.*
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5. *Understanding Chloride Percentages*, NRMCA Publication No. 173, NRMCA, Silver Spring, MD, *www.nrmca.org.*

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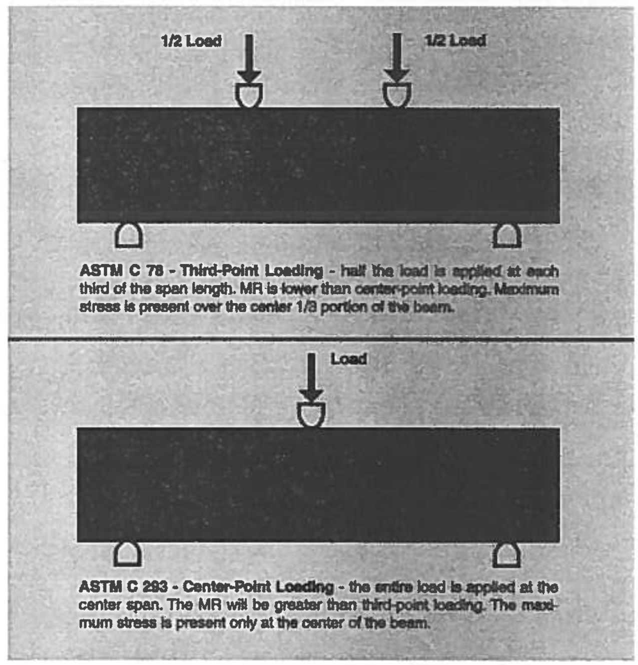
What, Why & How?
Flexural Strength of Concrete

CONCRETE IN PRACTICE — CIP 16

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%.



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.

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 Use Flexural 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 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 =

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

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 used for concrete structures.

> *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.

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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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NRMCA

What, Why & How?

Flowable Fill Materials

CONCRETE IN PRACTICE **CIP 17**

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

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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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What, Why & How?

Radon Resistant Buildings

CONCRETE IN PRACTICE CIP 18

WHAT is Radon?

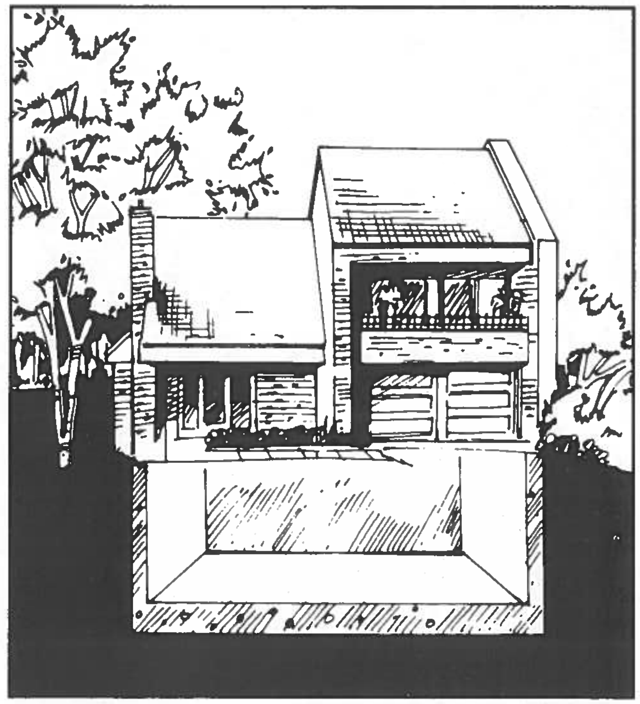
Radon is a colorless, odorless, radioactive gas which occurs naturally in soils in amounts dependent upon the geology of the location. The rate of movement of radon through the soil is dependent primarily upon soil permeability and degree of saturation, and differences in air pressure within the soil. 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]

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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]

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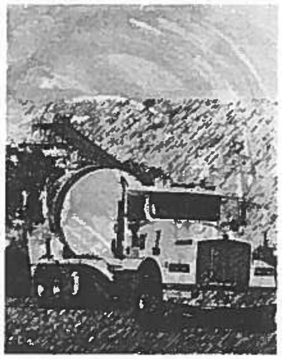


NRMCA

What, Why & How?
Curling of Concrete Slabs

CONCRETE IN PRACTICE CIP 19

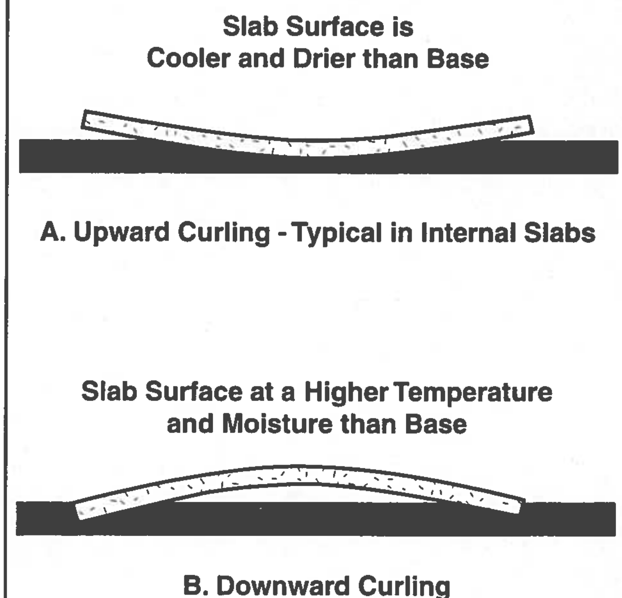
WHAT is Curling?

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 strength 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.
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 the slab, 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 alternative 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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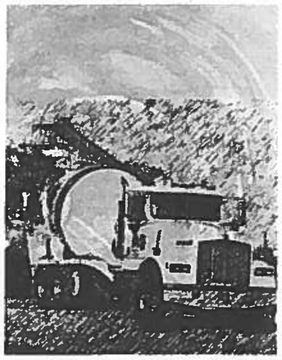

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What, Why & How?
Delamination of Troweled Concrete Surfaces

CONCRETE IN PRACTICE **CIP 20**

WHAT are Delaminations?

In most delaminated concrete slab surfaces, the top 1/8 to 1/4 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 (see CIP 13), but much larger in area.

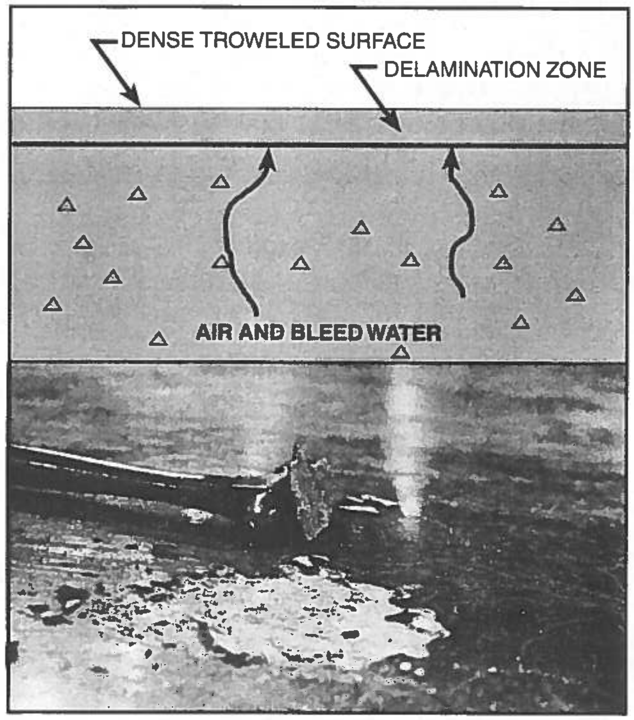
Delaminations form during final troweling. They are more frequent in early spring and late fall when concrete is placed on a cool subgrade with rising daytime temperatures, but they can occur at anytime depending on the concrete characteristics and the finishing practices used.

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.

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 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



Delaminated Concrete

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 Delaminations

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 the slab, other procedures may be necessary (see CIP 29).

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. Do not place concrete directly on vapor retarders.
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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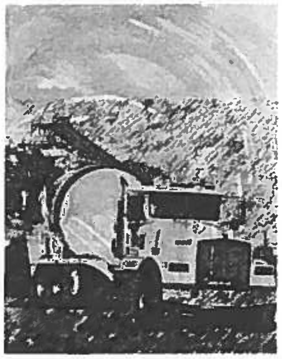


NRMCA

What, Why & How?
Loss of Air Content in Pumped Concrete

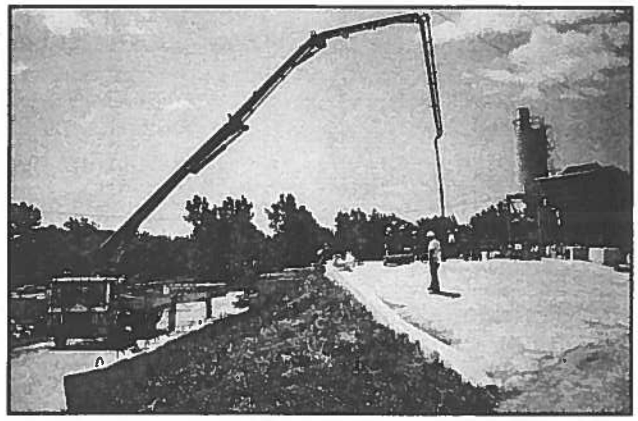
CONCRETE IN PRACTICE CIP 21

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 $5^{1}/_{2}$ sack concrete of moderate slump.



HOW to Prevent Air 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.

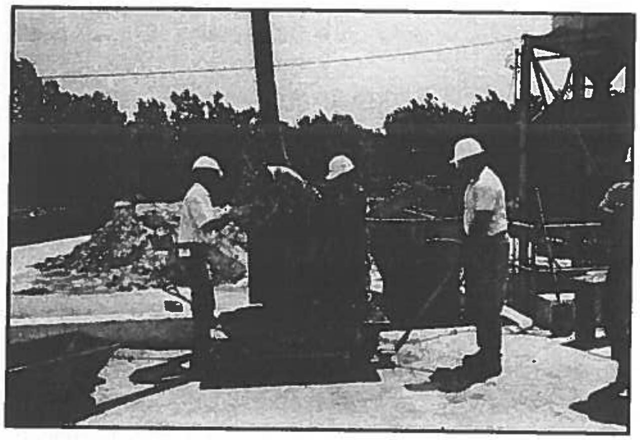
e) Reduce the rubber hose size from 5 to 4 in. A transition pipe may be needed to avoid blockages.

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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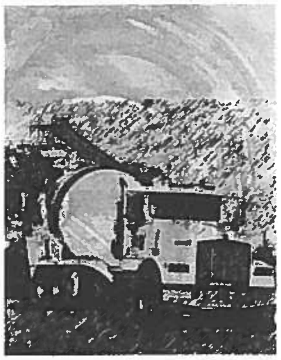


NRMCA

What, Why & How?

Grout

CONCRETE IN PRACTICE **CIP 22**

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.

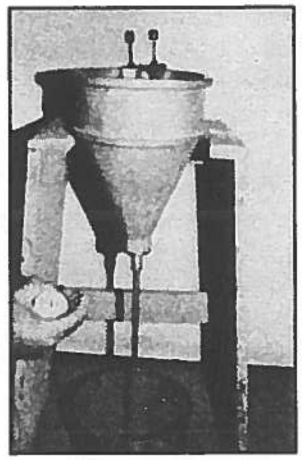
WHY is Grout Used?

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.

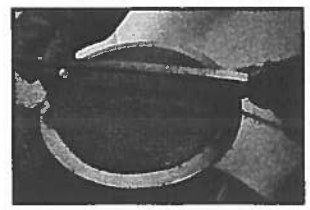
HOW to Specify Grout

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.

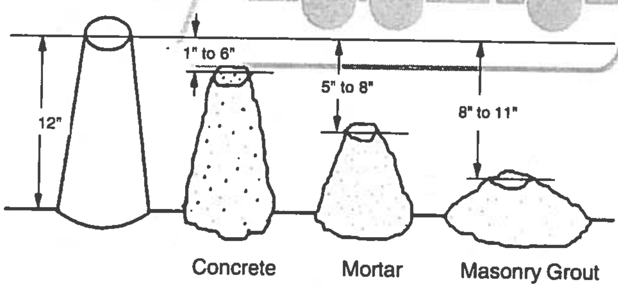
Consistency of masonry grout may be measured with a slump cone (ASTM C 143), and slumps of 8-11 in. are suggested. This is particularly applicable for grouts containing 1/2 in. or smaller coarse aggregate.

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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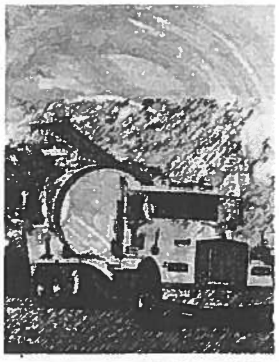


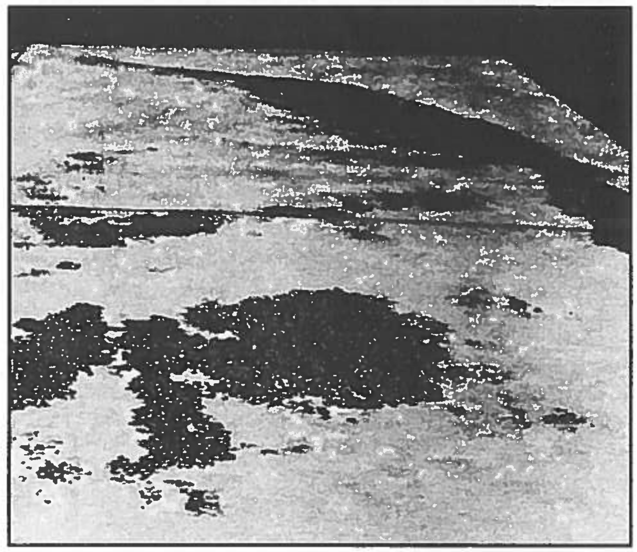
NRMCA

What, Why & How?
Discoloration

CONCRETE IN PRACTICE CIP 23

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 densifying 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.

References

1. "Surfaces Discoloration of Flatwork," Greening, N. R. and Landgren, R., *Portland Cement Association Research Department Bulletin RX 203,* 1966.
2. "Discoloration of Concrete, Causes and Remedies," Kosmatka, S. H., *Concrete Products,* April 1987.
3. "Discoloration of Concrete Flatwork," Neal, R. E., Lehigh Portland Cement Company, 1977.
4. "Removing Stains and Cleaning Concrete Surfaces," PCA, 1988.
5. "Discoloration: Myths, Causes and Cures," Rech, D. P., Owl Rock Products, 1989.
6. "Removing Stains from Mortar and Concrete," *Corps of Engineers Miscellaneous Paper C-6808.*
7. "Discolored Concrete Surfaces," Goeb, Eugene O., *Concrete Products,* Vol. 96, No. 2, February, 1993.

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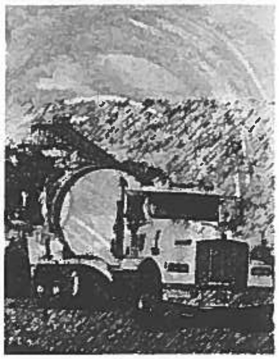

NRMCA

What, Why & How? Synthetic Fibers for Concrete

CONCRETE IN PRACTICE CIP 24

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.

References

1. ASTM C 1116 Standard Specification Fiber Reinforced Concrete and Shotcrete.
2. ASTM C 1018 Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber Reinforced Concrete (Using Beam with Third-Point Loading).
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.

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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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