

DURABLE CONCRETE FOR SIDEWALKS *

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DURABLE CONCRETE

What is "durable concrete"?

AS defined by the dictionary, durable concrete would have the quality of lasting or enduring and not being easily worn out. Specific properties of "durable concrete" would be:

1. Weather resistant
 - a. Wetting and drying
 - b. Freeze-thaw cycles
 - c. De-icing agents
2. Watertight
3. Wear resistant
4. Adequate strength

A well designed concrete mix, properly placed, finished, and cured *should*, without question, result in a durable concrete sidewalk or driveway.

A poor mix improperly placed and finished may result in scaling and disintegration of the surface within a few months or a few years.

The simple truth about concrete is that after hardening, it's nearly impossible to tell the difference between durable concrete and that of inferior quality — until some time later when severe exposure conditions or de-icers cause surface deterioration.

Poor durability

The "major causes" of poor durability of concrete exposed to the elements and de-icers in the New England area are listed below. No effort has been made to list them in order of importance.

1. Inadequate *cement factor*
2. Excessive *water content*
3. Insufficient *air entrainment*
4. Lack of *proper curing*
5. Improper *finishing* procedures
6. *De-icers*

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It is assumed that the quality and proportions of the aggregates are up to ASTM standards.

The Portland Cement Association, in an effort to dramatize the importance of the first four causes listed above, has labeled them the "Four 6's" of durable concrete.

The "Four 6's" are:

1. 6 bags (minimum) of cement per cu. yd.
2. 6 gallons (maximum) of water per bag of cement
3. 6 per cent air entrainment
4. 6 days (minimum) of continuous, moist curing

Educational Program in New Haven

Early this year it was decided to initiate an educational program in the New Haven area to educate ready mix producers, contractors, engineers and architects in the essentials of durable concrete. It was felt that a publicity program of this type would reduce future problems with deterioration and offset recent bad publicity.

Two concrete finishing demonstrations sponsored jointly by three New Haven ready mix producers were held on consecutive nights. The demonstrations were conducted by the Regional Constructional Superintendent for PCA who demonstrated and discussed various finishing techniques on five, 4-ft. square, panels of freshly placed concrete. A combined attendance of 170 contractors, engineers and architects attested to the interest in the program.

A ready mix drivers' seminar was held which was attended by 60 driver employees of these three producers. A complete 2½ hour program on the "Four 6's" of durable concrete was presented. The questions and heated discussion following the program pointed out the need and effectiveness of meetings such as this.

An advertising campaign was conducted from the first of July through the middle of August via newspaper and radio. The importance of the "Four 6's" was again stressed in three newspaper ads and an average of seven radio spots per week. An extension of this program is being considered for other areas in the New England District.

The First "6" — Cement Factor

Concrete is a dense mass of small and large aggregate bonded together by Portland cement. Some air voids and moisture are present in varying degrees.

The cement factor in bags per cubic yard of concrete generally varies from a low of 4 to a high of 8 bags. This may result in concrete strengths

ranging from 2,000 psi to 6,000 psi, and durability extending from very poor to excellent.

The question is, "What cement factor is necessary to help assure the required durability for slabs on the ground subjected to freezing and thawing and de-icers?" Our structural pamphlet (ST-89) on "Air-Entrained Concrete" shows an interesting set of photographs on the top of page 3. Six specimens with varying cement factors, half without entrained air, subjected to 5 years of exposure to a sulfate soil proved conclusively the importance of air entrainment and the increased durability with increasing cement factors.

The Connecticut Highway Department in their 1963 Specifications requires a class A concrete with 6.5 bags of cement per cubic yard for sidewalks.

The first "6" then, is a minimum of 6 bags of cement per cubic yard of concrete.

The increased cost for a bag of cement per cubic yard of concrete is about \$1.00. Based on a 4-in. slab, this figures out to less than 1.5¢ per square foot or a total increase in cost of less than 2%. This is cheap insurance against a scaled and deteriorating surface.

The Second "6" — Water Cement Ratio

The water cement ratio has long been recognized by engineers as an important factor in the quality of concrete. A minimum of about 3 gallons of water is required to fully hydrate one bag of cement. Some water in excess of this is necessary for workability and ease of transportation even though theoretically the quality and durability of the concrete is reduced. The water cement ratio may range from about 5 to 8 or 9 gallons of water per bag of cement.

This slide illustrates two cement paste cylinders each made with the same amount of cement but with water cement ratios of $3\frac{1}{2}$ and 10. Since they balance, the excess volume must consist of air voids which reduces the strength, durability, water tightness and wear resistance of the paste.

This slide shows the age-compressive strength relationship at various water cement ratios. Note the upper limits of 5.5 for water tightness and 6.0 for resistance to severe weathering. Note also that the compressive strength may be reduced by 1,000 psi with the addition of one gallon of water per bag of cement.

Slump is a measure of uniformity of the mix. These slides indicate a 1"-2" slump, a 3-in. slump (which is generally recommended for most slab work), and an 8-in. slump. The slump can be altered by changing the proportions of the mix as well as the water cement ratio.

This ready mix firm protects themselves with this paragraph on their delivery ticket and requires signed authorization from the contractor to add more water.

The second "6" is very important and stipulates a maximum of 6 gallons of water per bag of cement.

The Third "6" — Air Entrainment

Developed in the middle 1930's, adequate air-entrainment has been proven conclusively in the laboratory and field to increase substantially the resistance of concrete to freezing and thawing as well as de-icers. This is described in detail in ST89, "Air-Entrained Concrete"

Magnified sections of regular concrete on the left and air-entrained concrete on the right show the difference (tiny air bubbles) between the two. The pin heads offer a comparison in the size of the air voids.

The major advantages of air-entrainment in hardened and fresh concrete are listed on this slide.

These two boxes were constructed of the same mix except for air-entrainment in the top one which withstood twenty years of severe weather exposure considerably better than the non-air-entrained lower box.

This sketch depicts the physical reaction of freezing water in concrete and how proper air-entrainment accommodates the expansion of freezing water.

Surface bleed water is materially reduced with air-entrained concrete.

Various methods of controlling the air content in plastic concrete are illustrated in this slide.

The Chace Air Indicator is a very simple and effective means of determining the air content of plastic concrete.

The third "6" is extremely important, requiring 6 per cent air-entrained concrete.

The Fourth "6" — Curing

Properties of concrete such as resistance to freezing and thawing, strength, water tightness, wear resistance, and volume stability improve with age as hydration of the cement continues. The improvement is rapid at early ages and continues more slowly for an indefinite period. Two conditions are required: (1) the presence of moisture, and (2) a favorable temperature. Evaporation of water causes concrete to shrink, thus creating tensile stresses at the drying surface. If these stresses develop before the concrete has attained adequate strength, surface cracking may result.

Curing effects

Loss of water from fresh concrete may also cause the cement hydration to stop at an early age resulting in lower strength, more permeable concrete.

The effects of water cement ratio and curing on concrete permeability are illustrated in this slide.

General curing requirements are listed in this slide.

Methods of curing concrete are listed here.

The fourth and last "6" dictates a minimum of 6 days' continuous, moist curing.

Laboratory studies have shown the need for a minimum 7-day cure at 70° F. with types I and II cement (with or without CaCl) and with type III cement for durable scale-resistance concrete. A minimum cure of 14 days is necessary with types I and II cement at 40° F and 7 days if 2% CaCl is used or type III cement.

After curing, a period of air drying greatly increases the resistance of air-entrained concrete to de-icers. For this reason curing methods that allow drying at the completion of the curing period are preferable for fall paving on all projects where de-icers will be used.

A good rule of thumb for the age for the safe use of de-icers is: the curing period plus 30 days.

It may seem odd, but it's a fact, that sufficient moisture is necessary in concrete during the curing period but later on is unnecessary and may in fact be a contributing factor to concrete deterioration.

Finishing Procedures

The common tools for finishing small areas of concrete are the strike-off, darby, magnesium float, groover, edger and steel trowel.

This sequence of finishing operations for concrete floors may also be applied in part to sidewalks and other slabs. Placing the concrete consists of consolidation (with a shovel or vibrator), strike-off, and darbying or initial floating. The concrete is now reasonably smooth after these operations, done in rapid succession, are finished.

The lapse of time at this point is extremely important to allow excessive bleed water and surface moisture to evaporate from the surface. The basic rule of finishing concrete is: "if *any operation* is performed on the surface while the bled water is present, serious scaling, dusting or crazing can result". This is a fundamental fact of finishing concrete and cannot be ignored.

If the excessive surface moisture is floated or troweled into the surface, the water cement ratio of the concrete at the surface may be increased to extreme limits of 10 or 12 gallons per bag of cement. This would result in a very weak and low quality concrete surface unable to resist severe weathering and de-icers.

Once the water sheen has disappeared the other operations, edging, grooving, floating and troweling can be performed.

De-icers

Properly air-entrained concrete mixed and placed in accordance with the "Four 6's", properly finished and cured will resist severe weathering and de-icers for many, many years.

There are certain chemical de-icers other than calcium chloride and sodium chloride which have been marketed in the last couple of years and advertised for their lawn fertilizing characteristics. This is true. They are good fertilizers, but they are murder on any and all kinds of concrete. They will attack any type of concrete and therefore should not be used as de-icers under any circumstances.

These destructive chemicals contain large quantities of *ammonium sulphate* or *nitrate*. These ammonium salts are good fertilizers but should not be used on concrete.

Surface treatments that can be applied for additional protection to existing concrete are described in "Scale-Resistant Concrete Pavements" (HB31) and "Protection of Existing Concrete Pavements from Salt and Calcium Chloride" (HB-1). These treatments are generally two applications of a linseed oil mixture applied to a clean and reasonably warm surface.

Summary

The "Four 6's" of durable concrete:

1. 6 bags (min.) of cement per cubic yard
2. 6 gallons (max.) of water per bag of cement
3. 6 per cent air entrainment
4. 6 days (min.) of continuous, moist curing

Two other major factors:

5. Proper finishing *only* after surface moisture has evaporated.
6. Proper use of calcium chloride and sodium chloride as de-icers
— *no* ammonium salts.

Gentlemen, it's up to all of us in one way or another, as to how concrete slabs, exposed to the weather and de-icing salts, perform over a period of years. Most concrete looks the same after it has been placed and hardened.

Will your project look like this parking garage apron after 7 years of cycles of freezing and thawing and exposure to de-icing salts. . . or will it look like this badly scaled and deteriorated sidewalk?