

A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete

Reported by ACI Committee 515

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This Guide updates and expands the scope of the committee report "Guide for the Protection of Concrete Against Chemical Attack by Means of Coatings and Other Corrosion Resistant Materials," which appeared in the December 1996 ACI JOURNAL. The previous Guide has been revised and is found in Chapter 6 of this Guide entitled "Protective Barrier Systems." In addition, there are new chapters on "Waterproofing Barrier Systems," "Dampproofing Barrier Systems," and "Decorative Barrier Systems." A separate chapter on conditioning and surface preparation of concrete is included because it is relevant to all the other chapters.

This Guide is not to be referenced as a complete unit.

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Foreword

ACI Committee 515 was organized in 1936 and published a report "Guide for the Protection of Concrete Against Chemical Attack by Means of Coatings and Other Corrosion Resistant Materials," in the De-

cember 1966 ACI JOURNAL. William H. Kuenning was chairman when this Guide was published. Albert M. Levy was chairman from 1974 to 1977 when some of the information, found in the chapters on "Waterproofing Barrier Systems" and "Dampproofing Barrier Systems," was developed.

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CHAPTER 1-INTRODUCTION

1.1 -General discussion

Many concrete structures are designed and built to (1) contain water within the structure, or (2) maintain dry conditions within the structure when it is subject to water conditions on the outside. Since concrete is not always completely impermeable to water and since concrete may sometimes develop cracks after placement, it is sometimes necessary to cover the surface with a barrier material to meet these requirements. In this Guide, they will be identified as waterproofing barrier systems (Chapter 4) and dampproofing barrier systems (Chapter 5). See definitions in Sections 2.1.1 and 2.1.2 and discussion in Sections 2.2 and 2.3.

Some concrete structures may be subjected to chemical attack on one or more surfaces by water, acids, alkalis, salt solutions, or a wide variety of organic chemicals. Damage may be merely surface discoloration or surface roughening, or it may be as catastrophic as acid attack with the resulting loss of structural integrity. The affected surfaces are generally covered with barrier materials. These materials with the supporting concrete are designated in Chapter 6 of this Guide as protective barrier systems. See discussion in Sections 1.2, 2.4, and 2.5.

Some concrete surfaces require a change in color for esthetic reasons. A wide variety of paints are commercially available for this purpose. In this Guide they will be called decorative paint barrier systems (Chapter 7). See Sections 2.1.4 and 2.6.

All the barrier systems discussed in this Guide will be limited to those that are made up of polymeric cementitious and ceramic materials.

1.2-The systems concept for barriers

To understand the factors affecting the performance of the various barrier systems, it is necessary to consider them not isolated but as part of a whole. As an example, consider a protective coating system for a concrete structure below grade; the specific elements are: the barrier material, the interface of the barrier and concrete surface, concrete to a depth of $\frac{1}{4}$ in. (6 mm), the remainder of the concrete, the stability of the ground supporting it, and the ground water pressures (see Section 6.2 for more details).

Awareness of the systems concept will make one appreciate that selection of a barrier material is only one of many interrelated steps necessary to insure satisfactory performance. Equally important are placement, consolidation curing of the concrete, surface cleanliness, surface preparation, application procedures, and inspection.

A decision whether to use a barrier and its selection should be made when the concrete structure is being designed. Configuration of the structure, construction methods, and job sequencing can affect barrier installation and quality. Barrier penetrations can be minimized and the barrier aspects of the job will be better planned.

Placement and curing of the concrete should be in accordance with ACI 304 and ACI 308.4¹⁵ This should be followed by the appropriate surface preparation to remove any weak concrete, laitance, and foreign material.

This Guide will provide the best available information to assist in the selection, placement, installation and inspection of these barrier systems. Suggestions for the design and fabrication of the concrete structures that are to receive a barrier system will also be included. The goal of this Guide is to make the reader aware of the factors insuring satisfactory barrier performance.

1.3-Barrier performance difficult to define

There are no formulae, such as those available to designers of concrete structures, that can be used in the selection, placement, application, and inspection of barrier systems because many of the factors affecting barrier performance are difficult to define and are intangible factors. Structural engineers introduce strength reduction factors, load factors, and factors of safety into their design formulae to allow for variations in manufacturing or construction, and to compensate for those aspects of the design that cannot be precisely predicted.

Surface cleanliness is a major factor affecting adhesion and subsequent performance of the barrier system, and yet we are unable to quantify it. The reader should be aware that the application of a barrier system is really an art not a science. Once this is

recognized, action as outlined in this Guide can be taken to make sure the barrier system will meet the performance expectations of the owner or agency.

1.4-Economic factors for barrier selection

It is important for the owner or agency to recognize that selection, placement, installation, and inspection of a barrier system can be dominated by economic considerations to the detriment of performance. There may be pressures to select and install a barrier system that has the lowest initial cost per unit. However, these barriers may have a low performance potential. In addition to initial cost, some attention should be given to determine the cost of replacing a barrier system failing prematurely and to other costs associated with the failure. Other costs may include damage to concrete structures or water damage to equipment or excavating to expose the waterproofing.

Selection of a barrier system should be based upon the life-time performance potential giving the lowest annual cost per unit per year. A system that costs less on an annual basis will most likely result in higher initial cost because the materials and application labor used may be more expensive, or a larger quantity of material may be needed.

In addition, selection of a qualified applicator or use of an inspection program may increase initial costs but not annual costs. The manufacturer and applicator of the barrier material should be selected on the basis of past performance, financial responsibility, technical reliability, capability and willingness to supply technical assistance, and reputation for standing behind their product and work.

1.5-Inspection during application

In conjunction with the decisions to select a barrier material and an applicator, plans should be formulated for establishing a suitable inspection program to oversee the surface preparation and application work, and to make sure the barrier is applied in accordance with the specification. Inspection should commence before the barrier is installed and the final inspection should be made after the barrier has been placed. Use technical assistance available from the materials manufacturer or retain an independent inspection agency familiar with the specified barrier system.

1.6-Safety requirements

Appropriate safety requirements should be followed with respect to all materials, operations and procedures described in this Guide.^{1,2}

Plastic and rubber barrier surfaces may be slippery, especially when wet, and could be a safety hazard to personnel. The skid resistance of a barrier surface can be increased as required. A portable tester, identified as the NBS-Brungraber Slip-Resistance Tester, for the evaluation of the slip resistance of surfaces has been developed by the Na-

tional Bureau of Standards.³ Also, the barrier manufacturer should be contacted for recommendations.

References

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CHAPTER 2-BARRIER SYSTEMS: TYPES AND PERFORMANCE REQUIREMENTS

2.1-Definitions of barrier systems

2.1.1 Waterproofing barrier systems-Waterproofing is a treatment of a surface or structure to prevent the passage of water under hydrostatic pressure¹ (see Chapter 4). Waterproofing barrier systems may be placed on the positive or negative side (see Fig. 2.1.1).

2.1.1.1 Positive side barrier systems-Positive side barrier systems are placed on the same side as the applied hydrostatic pressure (See Table 4.2).

2.1.1.2 Negative side barrier systems-Negative side barrier systems are placed on the side opposite to the applied hydrostatic pressure [See Table 4.2).

2.1.2 Dampproofing barrier systems-Dampproofing is a treatment of a surface or structure to resist the passage of water in the absence of hydrostatic pressure¹ (see Chapter 5). Another definition of dampproofing given in ACI Special Publication 19² is: "Treatment of concrete or mortar to retard the passage or absorption of water, or water vapor, either by application of a suitable coating to exposed surfaces,

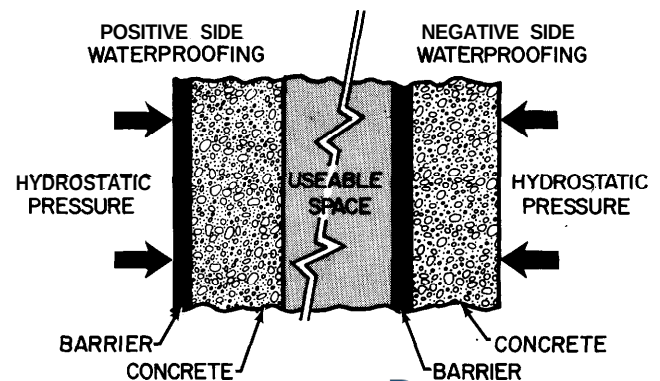


Fig. 2.2.1-Comparison of positive side and negative side waterproofing.

or by use of a suitable admixture or treated cement.” As these definitions indicate, dampproofing will only reduce the rate of transmission of water through concrete. The use of admixtures or special cements for dampproofing is not within the scope of this Guide.

2.1.3 Protective barrier systems—Protective barrier systems are used to protect concrete from degradation by chemicals and subsequent loss of structural integrity, to prevent staining of concrete, or to protect liquids from being contaminated by the concrete (see Chapter 6).

2.1.4 Decorative paint barrier systems—Decorative paint barrier systems are used to stabilize or change the appearance or color of a concrete surface for esthetic reasons (see Chapter 7).

2.2-When waterproofing is used

Waterproofing is normally used to prevent leakage of water into, through, or out of concrete under hydrostatic pressure. If freezing and thawing conditions exist, as in above-grade applications or if water is carrying aggressive chemicals which attack reinforcing steel or concrete, then the waterproofing barrier will be used to prevent leakage into the concrete. If a dry surface is required for applying coatings, then waterproofing could be used to prevent moisture from leaving the concrete. Waterproofing is also used to minimize unsightly carbonates or efflorescence.

2.2.1 Water leakage into and through concrete—Water may be forced through concrete by hydrostatic pressure, water vapor gradient, capillary action, wind-driven rain, or any combination of these. This movement is aggravated by porous concrete, cracks or structural defects, or joints that are improperly designed or installed. Leakage of water into structures may cause structural damage, and invariably causes damage to the contents of the structure. Leakage of water out of water-storage structures may also cause structural damage or damage to adjacent facilities. Waterproofing membranes are intended primarily to prevent the passage of water in liquid form. They also retard the passage of water vapor in varying degrees depending on the type of membrane.

2.2.2 Water leakage out of concrete—To prevent moisture from leaving the concrete and coming in contact with moisture sensitive materials, the waterproofing barrier should be placed on the concrete surface on which the moisture sensitive material will be applied. This could prevent delamination, blistering, and deterioration of moisture sensitive paints, wall and floor coverings, and adhesives.

2.2.3 Minimize efflorescence—Efflorescence is a deposit of salts, usually white, formed on a surface, the substance having emerged in solution from within concrete or masonry and deposited by evaporation.² Also, soluble salts of various kinds, chiefly sulfates, may be carried by water into the concrete from the soil or other environmental source. These

salts may later be brought to an exposed surface as moisture moves out of the concrete. Barrier systems help prevent efflorescence on the surface of concrete walls.

2.3-When dampproofing is used

A dampproofing barrier system is used to perform the same functions as a waterproofing system but cannot be used to protect against water under pressure. A drainage system may be required to prevent the development of a head of water. Dampproofing is a low-cost system because the material thickness is relatively low and minimum surface preparation is required.

A dampproofing barrier system will minimize water vapor transmission through concrete as long as the concrete will not be subjected to a continuous or even an intermittent head of water.

2.4-When protective barrier systems are used

Protective barrier systems are required to protect concrete from deterioration when exposed to chemicals (see Sections 2.4.1, 2.4.2, and 2.4.3). See References 3, 4, and 5 for more comprehensive information on the durability of concrete. In some cases a barrier is required to prevent chemicals from being contaminated when they contact a concrete surface.

Waterproofing and dampproofing barrier systems, as well as decorative painting barrier systems, may also perform roles as protective barriers because they cover a concrete surface so that direct contact with aggressive chemicals is greatly reduced or in some cases eliminated. However, when the primary function of a barrier system is to improve the durability of concrete, other types of barrier systems are generally used and these are described in Chapter 6.

2.4.1 Acid and alkali attack—Acids, some salt solutions, and water (depending on purity and temperature) will react with the $\text{Ca}(\text{OH})_2$ in the hydrated portland cement binder of concrete to form water soluble reaction products resulting in the disintegration of the concrete. Strong alkalies (over 20 percent) attack other constituents in the cement resulting in concrete disintegration. Section 2.5 discusses the susceptibility of concrete to attack by chemicals.

The rate of attack will not only depend on the above reaction but also on how quickly the reaction products are leached or removed from the surface and on the ability of the chemical to penetrate into the hardened cement paste. Limestone and dolomite aggregates are susceptible to acid attack and may also cause disintegration of the concrete, but in other instances they may function as sacrificial materials and prolong service life.

2.4.2 Sulfate attack—Sulfate solutions (sodium, potassium, magnesium) can cause disintegration of concrete by reacting with the tricalcium silicate in portland cement to form calcium sulfo-aluminate (ettringite) which has a volume larger than the original reactant materials. The internal volume increase

can result in cracking of the concrete. Sulfate attack is normally controlled by using sulfate resistant portland cement and/or pozzolan materials such as fly ash. Sulfate resistance is also improved by using a dense concrete with a low water-cement ratio.³

2.4.3 Corrosion of embedded steel-Penetration of chemical or salt solutions through concrete is likely to cause localized corrosion of reinforcing steel. Formation of rust results in expansive pressures which cause deterioration of the concrete near the steel.³ Chapter 4 of Reference 3 above discusses this problem and possible solutions. Two of the solutions involve the use of barrier systems. A protective barrier may be factory applied to reinforcing steel before use and/or a waterproofing barrier may be applied to the positive side of the concrete.

2.4.4 Product contamination-Solutions, such as high purity water or chemicals, may become contaminated by direct contact with concrete. Also, the flavor and odor of food products may be adversely affected by concrete.

2.5-Susceptibility of concrete to attack by chemicals

2.5.1 Factors affecting attack⁶-In general, the vulnerability of concrete to chemical attack results from three of its characteristics: permeability, alkalinity, and reactivity.

Permeability to liquids and gases varies considerably with different concretes. Even the best concrete has some small degree of permeability. Permeability increases rapidly with increasing water-cement ratio and with decreasing moisture curing time. Penetration of fluids into the concrete is sometimes accompanied by chemical reactions with cement, aggregates, and/or embedded steel (if present). Leaching of cement hydration compounds, or deposition of extraneous crystals or crystalline reaction products can also degrade the system.

The alkaline, hydrated portland cement binder reacts with acidic substances. This reaction is usually accompanied by the formation and removal of soluble reaction products, resulting in disintegration of the concrete. When the reaction products are insoluble, deposits are formed on the concrete surface or in the concrete causing a considerably reduced reaction rate.

2.5.1.1 Rate and extent of attack-Usually the rate of attack will be increased by an increase in the concentration of aggressive agents in solution.

The pH of a solution indicates whether it is alkaline, neutral, or acidic. A neutral solution has a pH of 7. Acid solutions have pH values less than 7 and alkaline ones have values over 7. When the pH decreases from 7, the solution becomes more acidic and it will become more aggressive in its attack on concrete.

The physical state of the chemical agent is also of significance. Dry, nonhygroscopic solids do not attack dry concrete, but some will attack moist con-

crete. A moist, reactive solid can attack concrete, as can aggressive liquids and solutions. Dry gases, if aggressive, may come into contact with sufficient moisture within the concrete to make attack possible. Moist, aggressive gases would tend to be more destructive.

Temperature may affect the rate of attack in two different ways. The common effect is that chemical activity usually increases exponentially, approximately doubling with each 10 C (18 F) rise in temperature. Temperature may also affect the rate of attack indirectly. As temperature rises, the moisture content of the concrete is reduced, making it drier but more permeable to additional fluid. As temperature falls, it may sometimes cause sufficient normal shrinkage to open small cracks and allow greater penetration of liquid into the concrete.

In addition to considering the rate of attack, it is desirable to determine how extensive the attack might be. For example a concrete structure may be placed in an acid soil, but if the acidity is not replenished, the available acid may be quickly neutralized with little or no damage to the concrete.

Alternate wetting and drying can be harmful; increased destruction due to alkali-aggregate reaction is possible. Dissolved substances may migrate through the concrete and deposit at or near a surface from which evaporation occurs. The deposit may be the original substance or some reaction product formed in the concrete. This effect can be seen in the familiar "efflorescence" on walls of concrete, brick, or stone.

Salt solutions can also be more disruptive to concrete subjected to freezing and thawing than water alone. This is commonly observed after the application of deicing salts to non-air-entrained highway pavements. However, damage from either can be minimized by the use of an adequate amount of intentionally entrained air in an otherwise high quality concrete producing air bubbles of the correct size, spacing, and distribution.

2.5.2 Materials that attack concrete-Table 2.5.2 gives a summary of the effects of many materials on concrete. This information, based both on literature sources and experience, must be considered a guide to assist in designing a test program using the concrete mixes and chemicals for a specific application.

In addition to individual organic and mineral acids which may attack concrete, acid-containing or acid-producing substances such as acidic industrial wastes, silage, fruit juices, sour milk, salts of weak bases, and some untreated waters may also cause deterioration of concrete.

Most ammonium salts are destructive because in the alkaline environment of concrete they release ammonia gas and hydrogen ions. These are replaced by dissolving calcium from the concrete. The result is a leaching action, much like acid attack.

Animal wastes contain substances which may oxidize in air to form acids which attack concrete. The

Table 2.5.2-Effect of chemicals on concrete (see end of Table 2.5.2 for special notations)

Material	Effect	Material	Effect
*Acetic acid, all concentrations	Disintegrates slowly	Ashes	Harmful if wet, when sulfides and sulfates leach out (see sodium sulfate)
Acetone	Liquid loss by penetration. May contain acetic acid as impurity (which see)	Ashes, hot	Cause thermal expansion
Acid waters (pH of 6.5 or less) (a)	Disintegrates slowly. In porous or cracked concrete, attacks steel	Automobile and diesel exhaust gases (n)	May disintegrate moist concrete by action of carbonic, nitric, or sulfurous acid
*Alcohol	See ethyl alcohol, methyl alcohol	*Baking soda	See sodium bicarbonate
Alizarin	Not harmful	Barium hydroxide	Not harmful
*Almond oil	Disintegrates slowly	Bark	See tanning bark
*Alum	See potassium aluminum sulfate	*Beef fat	Solid fat disintegrates slowly, melted fat more rapidly
Aluminum chloride	Disintegrates rapidly. In porous or cracked concrete, attacks steel	*Beer	May contain, as fermentation products, acetic, carbonic, lactic, or tannic acids (which see)
*Aluminum sulfate	Disintegrates. In porous or cracked concrete, attacks steel	Benzol (benzene)	Liquid loss by penetration
*Ammonia, liquid	Harmful only if it contains harmful ammonium salts (see below)	Bleaching solution	See specific chemical, such as hypochlorous acid, sodium hypochlorite, sulfurous acid, etc.
Ammonia vapors	May disintegrate moist concrete slowly or attack steel in porous or cracked moist concrete	*Borax	Not harmful
Ammonium bisulfate	Disintegrates. In porous or cracked concrete, attacks steel	*Boric acid	Negligible effect
Ammonium carbonate	Not harmful	*Brine	See sodium chloride or other salt
*Ammonium chloride	Disintegrates slowly. In porous or cracked concrete, attacks steel	Bromine	Gaseous bromine disintegrates. Liquid bromine disintegrates if it contains hydrobromic acid and moisture
Ammonium cyanide	Disintegrates slowly	*Buttermilk	Disintegrates slowly
Ammonium fluoride	Disintegrates slowly	Butyl stearate	Disintegrates slowly
Ammonium hydroxide	Not harmful	Calcium bisulfite	Disintegrates rapidly
Ammonium nitrate	Disintegrates. In porous or cracked concrete, attacks steel	*Calcium chloride	In porous or cracked concrete, attacks steel. (b) Steel corrosion may cause concrete to spall
Ammonium oxalate	Not harmful	*Calcium hydroxide	Not harmful
*Ammonium sulfate	Disintegrates. In porous or cracked concrete, attacks steel	Calcium nitrate	Not harmful
Ammonium sulfide	Disintegrates	*Calcium sulfate	Disintegrates concrete of inadequate sulfate resistance
Ammonium sulfite	Disintegrates	Carbazole	Not harmful
Ammonium superphosphate	Disintegrates. In porous or cracked concrete, attacks steel	Carbolic acid	See phenol
Ammonium thiosulfate	Disintegrates	*Carbon dioxide	Gas may cause permanent shrinkage (see also carbonic acid)
Animal wastes	See slaughter house wastes	*Carbon disulfide	May disintegrate slowly
Anthracene	Not harmful	*Carbon tetrachloride	Liquid loss by penetration of concrete
Arsenious acid	Not harmful	*Carbonic acid	Disintegrates slowly

Table 2.5.2-(Continued)

Material	Effect	Material	Effect
Castor oil	Disintegrates, especially in presence of air	*Cottonseed oil	Disintegrates, especially in presence of air
Chile saltpeter	See sodium nitrate	Creosote	Phenol present disintegrates slowly
China wood oil	Liquid disintegrates slowly.	Cresol	Phenol present disintegrates slowly
Chlorine gas	Slowly disintegrates moist concrete	Cumol	Liquid loss by penetration
Chrome plating solutions (o)	Disintegrates slowly	Deicing salts	Scaling of non-air-entrained or insufficiently aged concrete (b)
Chromic acid, all concentrations	Attacks steel in porous or cracked concrete	Diesel gases	See automobile and diesel exhaust gases
Chrysen	Not harmful	Dinitrophenol	Disintegrates slowly
*Cider	Disintegrates slowly (see acetic acid]	Distiller's slop	Lactic acid causes slow disintegration
Cinders	Harmful if wet, when sulfides and sulfates leach out (see, for example, sodium sulfate)	Epsom salt	See magnesium sulfate
Cinders, hot	Cause thermal expansion	*Ethyl alcohol	Liquid loss by penetration
Coal	Sulfides leaching from damp coal may oxidize to sulfurous or sulfuric acid, or ferrous sulfate (which see)	*Ethyl ether	Liquid loss by penetration
Coal tar oils	See anthracene, benzol, carbazole, chrysen, creosote, cresol, cumol, paraffin, phenanthrene, phenol, toluol, xylo	*Ethylene glycol	Disintegrates slowly (d)
Cobalt sulfate	Disintegrates concrete of inadequate sulfate resistance	Feces	See manure
*Cocoa bean oil	Disintegrates, especially in presence of air	*Fermenting fruits, grains, vegetables, or extracts	Industrial fermentation processes produce lactic acid. (e) Disintegrates slowly (see lactic acid)
*Cocoa butter	Disintegrates, especially in presence of air	Ferric chloride	Disintegrates slowly
Coconut oil	Disintegrates, especially in presence of air	Ferric nitrate	Not harmful
*Cod liver oil	Disintegrates slowly	Ferric sulfate	Disintegrates concrete of inadequate quality
Coke	Sulfides leaching from damp coke may oxidize to sulfurous or sulfuric acid (which see]	Ferric sulfide	Harmful if it contains ferric sulfate (which see)
Copper chloride	Disintegrates slowly	Ferrous chloride	Disintegrates slowly
Copper plating solutions (p)	Not harmful	Ferrous sulfate	Disintegrates concrete of inadequate sulfate resistance
Copper sulfate	Disintegrates concrete of inadequate sulfate resistance	Fertilizer	See ammonium sulfate, ammonium superphosphate, manure, potassium, nitrate, sodium nitrate
Copper sulfide	Harmful if it contains copper sulfate (which see)	Fish liquor	Disintegrates (f)
*Corn syrup	Disintegrates slowly	*Fish oil	Disintegrates slowly
Corrosive sublimate	See mercuric chloride	Flue gases	Hot gases (400-1100 F) cause thermal stresses. Cooled, condensed sulfurous, hydrochloric acids disintegrate slowly
		Foot oil	Disintegrates slowly
		*Formaldehyde, 37 percent	Formic acid, formed in solution, disintegrates slowly
		Formalin	See formaldehyde

Table 2.5.2-(Continued)

Material	Effect	Material	Effect
*Formic acid, 10 percent	Disintegrates slowly	Lignite oils	If fatty oils are present, disintegrates slowly
*Formic acid, 30 percent	Disintegrates slowly	*Linseed oils	Liquid disintegrates slowly. Dried or drying films are harmless
*Formic acid, 90 percent	Disintegrates slowly	Locomotive gases (r)	May disintegrate moist concrete by action of carbonic, nitric or sulfurous acids (see also automobile and diesel exhaust gases)
*Fruit juices	Hydrofluoric, other acids, and sugar cause disintegration (see also fermenting fruits, grains, vegetables, extracts)	Lubricating oil	Fatty oils, if present, disintegrate slowly
Gas water (g)	Ammonium salts seldom present in sufficient quantity to disintegrate	Lye	See sodium hydroxide
Gasoline	Liquid loss by penetration	Machine oil	Fatty oils, if present, disintegrate slowly
*Glucose	Disintegrates slowly	*Magnesium chloride	Disintegrates slowly. In porous or cracked concrete, attacks steel
*Glycerine	Disintegrates slowly	Magnesium nitrate	Disintegrates slowly
*Grain	See fermenting fruits, grains, vegetables, extracts	*Magnesium sulfate	Disintegrates concrete of inadequate sulfate resistance
*Honey	Not harmful	Manganese sulfate	Disintegrates concrete of inadequate sulfate resistance
Horse fat	Solid fat disintegrates slowly, melted fat more rapidly	Manure	Disintegrates slowly
Humic acid	Disintegrates slowly	*Margarine	Solid margarine disintegrates slowly, melted margarine more rapidly
*Hydrochloric acid, all concentrations	Disintegrates rapidly, including steel	Mash, fermenting	Acetic and lactic acids, and sugar disintegrate slowly
Hydrofluoric acid, all concentrations	Disintegrates rapidly, including steel	Mercuric chloride	Disintegrates slowly
Hydrogen sulfide	Not harmful dry. In moist, oxidizing environments converts to sulfurous acid and disintegrates slowly	Mercurous chloride	Disintegrates slowly
Hypochlorous acid, 10 percent	Disintegrates slowly	Methyl alcohol	Liquid loss by penetration
Iodine	Disintegrates slowly	Methyl ethyl ketone	Liquid loss by penetration
Kerosene	Liquid loss by penetration of concrete	Methyl isobutyl ketone	Liquid loss by penetration
*Lactic acid, 5-25 percent	Disintegrates slowly	*Milk	Not harmful. However, see sour milk
*Lamb fat	Solid fat disintegrates slowly, melted fat more rapidly	Mine water, waste	Sulfides, sulfates, or acids present disintegrate concrete and attack steel in porous-or cracked concrete
*Lard and lard oil	Lard disintegrates slowly, lard oil more rapidly	*Mineral oil	Fatty oils, if present, disintegrate slowly
Lead nitrate	Disintegrates slowly	Mineral spirits	Liquid loss by penetration
Lead refining solutions (q)	Disintegrates slowly	*Molasses	At temperatures ≥ 120 F, disintegrates slowly
Leuna saltpeter	See ammonium nitrate and ammonium sulfate	Muriatic acid	See hydrochloric acid
		*Mustard oil	Disintegrates, especially in presence of air
		Nickel plating solutions (v)	Nickel ammonium sulfate disintegrates slowly

Table 2.5.2-(Continued)

Material	Effect	Material	Effect
Nickel sulfate	Disintegrates concrete of inadequate sulfate resistance	Potassium hydroxide, 25 percent or over	Disintegrates concrete
Niter	See potassium nitrate	*Potassium nitrate	Disintegrates slowly
Nitric acid, all concentrations	Disintegrates rapidly	Potassium permanganate	Harmless unless potassium sulfate present (which see)
*Oleic acid, 100 percent	Not harmful	Potassium persulfate	Disintegrates concrete of inadequate sulfate resistance
Oleum	See sulfuric acid, 110 percent	Potassium sulfate	Disintegrates concrete of inadequate sulfate resistance
*Olive oil	Disintegrates slowly	Potassium sulfide	Harmless unless potassium sulfate present (which see)
Ores	Sulfides leaching from damp ores may oxidize to sulfuric acid or ferrous sulfate (which see)	Pyrites	See ferric sulfide, copper sulfide
Oxalic acid	Not harmful. Protects tanks against acetic acid, carbon dioxide, salt water. Poisonous. Do not use with food or drinking water	*Rapeseed oil	Disintegrates, especially in presence of air
Paraffin	Shallow penetration not harmful, but should not be used on highly porous surfaces like concrete masonry (u)	Rock salt	See sodium chloride
*Peanut oil	Disintegrates slowly	Rosin	Not harmful
Perchloric acid, 10 percent	Disintegrates	Rosin oil	Not harmful
Perchloroethylene	Liquid loss by penetration	Sal ammoniac	See ammonium chloride
Petroleum oils	Liquid loss by penetration. Fatty oils, if present, disintegrate slowly	Sal soda	See sodium carbonate
Phenanthrene	Liquid loss by penetration	Salt for deicing roads	See text. Also calcium chloride, magnesium chloride, sodium chloride
Phenol, 5-25 percent	Disintegrates slowly	Saltpeter	See potassium nitrate
*Phosphoric acid, 10-85 percent	Disintegrates slowly	*Sauerkraut	Flavor impaired by concrete. Lactic acid may disintegrate slowly
*Pickling brine	Attacks steel in porous or cracked concrete	Sea water	Disintegrates concrete of inadequate sulfate resistance. Attacks steel in porous or cracked concrete
Pitch	Not harmful	Sewage	Usually not harmful (see hydrogen sulfide)
*Poppy seed oil	Disintegrates slowly	Silage	Acetic, butyric, lactic acids (and sometimes fermenting agents of hydrochloric or sulfuric acids) disintegrate slowly
*Potassium aluminum sulfate	Disintegrates concrete of inadequate sulfate resistance	Slaughter house wastes (w)	Organic acids disintegrate
*Potassium carbonate	Harmless unless potassium sulfate present (which see)	Sludge	See sewage, hydrogen sulfide
*Potassium chloride	Magnesium chloride, if present, attacks steel in porous or cracked concrete	Soda water	See carbonic acid
Potassium cyanide	Disintegrates slowly	*Sodium bicarbonate	Not harmful
Potassium dichromate	Disintegrates	Sodium bisulfate	Disintegrates
Potassium hydroxide, 15 percent	Not harmful (h)	Sodium bisulfite	Disintegrates
		Sodium bromide	Disintegrates slowly

Table 2.5.2-(Continued)

Material	Effect	Material	Effect
Sodium carbonate	Not harmful, except to calcium aluminate cement	Sulfurous acid	Disintegrates rapidly
*Sodium chloride	Magnesium chloride, if present, attacks steel in porous or cracked concrete. (b) Steel corrosion may cause concrete to spall	Tallow and tallow oil	Disintegrates slowly
Sodium cyanide	Disintegrates slowly	Tannic acid	Disintegrates slowly
Sodium dichromate	Dilute solutions disintegrate slowly	Tanning bark	May disintegrate slowly if damp (see tanning liquor)
*Sodium hydroxide, 1-10 percent	Not harmful (h)	Tanning liquor	Disintegrates, if acid
*Sodium hydroxide, 20 percent or over	Disintegrates concrete	*Tartaric acid solution	Not harmful
Sodium hypochlorite	Disintegrates slowly	Tobacco	Organic acids, if present, disintegrate slowly
*Sodium nitrate	Disintegrates slowly	Toluol (toluene)	Liquid loss by penetration
Sodium nitrite	Disintegrates slowly	*Trichloroethylene	Liquid loss by penetration
Sodium phosphate (monobasic)	Disintegrates slowly	*Trisodium phosphate	Not harmful
Sodium sulfate	Disintegrates concrete of inadequate sulfate resistance	Tung oil	Liquid disintegrates slowly. Dried or drying films are harmless
Sodium sulfide	Disintegrates slowly	Turpentine	Mild attack. Liquid loss by penetration
*Sodium sulfite	Sodium sulfate, if present, disintegrates concrete of inadequate sulfate resistance	*Urea	Not harmful
Sodium thiosulfate	Slowly disintegrates concrete of inadequate sulfate resistance	Urine	Attacks steel in porous or cracked concrete
*Sour milk	Lactic acid disintegrates slowly	Vegetables	See fermenting fruits, grains, vegetables, extracts
*Soybean oil	Liquid disintegrates slowly. Dried or drying films harmless	Vinegar	Disintegrates slowly (see acetic acid)
Strontium chloride	Not harmful	Walnut oil	Disintegrates slowly
*Sugar	Disintegrates slowly	*Whey	Disintegrates slowly (see lactic acid)
Sulfite liquor	Disintegrates	*Wine	Not harmful. Necessary to prevent flavor contamination
Sulfite solution	See calcium bisulfite	Wood pulp	Not harmful
*Sulfur dioxide	With moisture forms sulfurous acid (which see)	Xylol (xylene)	Liquid loss by penetration
*Sulfuric acid, 10-80 percent	Disintegrates rapidly	*Zinc chloride	Disintegrates slowly
*Sulfuric acid, 80 percent oleum	Disintegrates	Zinc nitrate	Not harmful
		Zinc refining solutions (x)	Hydrochloric or sulfuric acids, if present, disintegrate concrete
		Zinc slag	Zinc sulfate (which see) sometimes formed by oxidation
		Zinc sulfate	Disintegrates slowly

Key to special notations-Table 2.5.2

*	Sometimes used in food processing or as food or beverage ingredient. Ask for advisory opinion of Food and Drug Administration regarding coatings for use with food ingredients.
a	Waters of pH higher than 6.5 may be aggressive if they also contain bicarbonates. (Natural waters are usually of pH higher than 7.0 and seldom lower than 6.0, though pH values as low as 0.4 have been reported. For pH values below 3, protect as for dilute acid.)
b	Frequently used as a deicer for concrete pavements. If the concrete contains too little entrained air or has not been aged more than one month, repeated application may cause surface scaling. For protection under these conditions, see "deicing salts."
c	Carbon dioxide dissolves in natural waters to form carbonic acid solutions. When it dissolves to extent of 0.9 to 3 parts per million it is destructive to concrete.
d	Frequently used as deicer for airplanes. Heavy spillage on runway pavements containing too little entrained air may cause surface scaling.
e	In addition to the intentional fermentation of many raw materials, much unwanted fermentation occurs in the spoiling of foods and food wastes, also producing lactic acid.
f	Contains carbonic acid, fish oils, hydrogen sulfide, methyl amine, brine, other potentially reactive materials.
g	Water used for cleaning coal gas.
h	However, in those limited areas of the United States where concrete is made with reactive aggregates, disruptive expansion may be produced.
n	Composed mostly of nitrogen, oxygen, carbon dioxide, carbon monoxide, and water vapor. Also contains unburned hydrocarbons, partially burned hydrocarbons, oxides of nitrogen, and oxides of sulfur. Nitrogen dioxide and oxygen in sunlight may produce ozone, which reacts with some of the organics to produce formaldehyde, peracetylnitrates, and other products.
o	These either contain chromium trioxide and a small amount of sulfate, or ammonium chromic sulfate [nearly saturated] and sodium sulfate.
p	Many types of solutions are used, including (a) Sulfate-Contain copper sulfate and sulfuric acid. (b) Cyanide-Contain copper and sodium cyanides and sodium carbonate. (c) Rochelle-Contain these cyanides, sodium carbonate, and potassium sodium tartrate. (d) Others such as fluoborate, pyrophosphate, amine, or potassium cyanide.
q	Contains lead fluosilicates and fluosilicic acid.
r	Reference here is to combustion of coal, which produces carbon dioxide, water vapor, nitrogen, hydrogen, carbon monoxide, carbohydrates, ammonia, nitric acid, sulfur dioxide, hydrogen sulfide, soot, and ashes.
u	Porous concrete which has absorbed considerable molten paraffin and then been immersed in water after the paraffin has solidified has been known to disintegrate from sorptive forces.
v	Contains nickelous chloride, nickelous sulfate, boric acid, and ammonium ion.
w	May contain various mixtures of blood, fats and oils, bile and other digestive juices, partially digested vegetable matter, urine, and manure, with varying amounts of water.
x	Usually contains zinc sulfate in sulfuric acid. Sulfuric acid concentration may be low (about 6 percent in "low current density" process) or higher (about 22-28 percent in "high current density" process).

saponification reaction between animal fats and the hydration products of portland cement consumes these hydration products, producing salts and alcohols, in a reaction analogous to that of acids.

Many agents attack concrete and destructively alter its chemical composition by means of reaction mechanisms which are only partially or incompletely understood. Sea water, perhaps largely because of its sulfate content, may be destructive to permeable concrete or those made with cement having a high tricalcium aluminate content. Some polyhydroxy organic compounds such as glycols, glycerol, and sugars slowly attack concrete.

2.5.3 Materials that do not attack concrete—There are a large number of chemicals which do not attack concrete. Many of these are listed in Table 2.5.2.

Among the common neutral salts which do not attack concrete are most carbonates and nitrates, some chlorides, fluorides, and silicates. Lime water is usually beneficial to concrete because it promotes hydration without removal of lime from the concrete. Other weak alkaline solutions are not usually harmful. Products derived from petroleum, when free of fatty oil additives or other potentially acidic materials, are normally harmless to mature concrete. Some of these materials can, however, cause undesirable discoloration.

2.6-When decorative painting barrier systems are used

In addition to changing color or appearance of the concrete surface for esthetic reasons, a decorative paint barrier can minimize concrete surface degradation by rust stains from improperly filled form-tie holes, from embedded steel and from mold or algae growing on a moist surface. These materials may also function as a protective barrier system as defined in Section 6.1 in Chapter 6.

References

1. "Standard Definitions of Terms Relating to Bituminous and Other Organic Materials for Roofing, Waterproofing, and Related Building or Industrial Uses," (ASTM D 1079-74), ASTM, Philadelphia, 1974.
2. ACI Committee 116, "Cement and Concrete Terminology," (ACI 116R-78), American Concrete Institute, Detroit, 1978, 50 pp.
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4. Biczok, Imre, *Concrete Corrosion-Concrete Protection*, 8th Edition, Akademiai Kiado, Budapest, 1972, 545 pp.
5. Woods, Hubert, *Durability of Concrete Construction*, ACI Monograph No. 4, American Concrete Institute/Iowa State University Press, Detroit, 1968, 190 pp.
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Additional sources of information

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CHAPTER 3-CONCRETE CONDITIONING AND SURFACE PREPARATION

3.1-General requirements

This chapter provides recommendations for conditioning or repairing the concrete surface by removing surface defects that can affect the performance of the barrier system and for surface preparation by chemical and blast cleaning methods to insure good adhesion between the barrier material and the concrete. The documents issued by ACI Committees 301, 302, and 311 should help to assure the desired concrete quality.^{1,2,12} New concrete must be structurally sound, dry and clean to prevent loss of bond. However, some proprietary barrier systems can be applied to green or wet concrete, but their use should be based on the recommendations and detailed instructions of the materials manufacturer.

The three types of surface contamination that can result in poor adhesion of the barrier material to the concrete are described below.

3.1.1 Release agents on forms—Release agents on forms, such as oil, wax, grease and silicone, which will transfer to the concrete surface during placement, should not be used if a barrier system will be applied later. If materials are not completely removed they cause poor adhesion between the barrier system and the concrete. Since these materials are usually invisible, their complete removal may be difficult. In addition, the procedure for their removal will depend on the nature of the specific contaminant. Proprietary paint systems applied to forms and formulated to prevent contamination of the concrete surface should be used.

3.1.2 Curing compounds—Curing compounds should not be used on concrete surfaces on which an adhesive-bonded barrier is to be applied unless it can be completely removed before application of the barrier, or unless the curing compound is compatible with the barrier material and the concrete surface.³

Liquid, membrane-forming curing compounds consisting of waxes, resins, chlorinated rubber and solvents are used extensively for curing concrete. Recently, curing compounds based on two component, epoxy resin paints have been developed which may be more compatible with barrier systems; however, field testing is necessary to establish compatibility.

3.1.3 Admixtures in concrete—Some special purpose admixtures, such as water-immiscible chemicals intended to retard evaporation of water during cure, when added to the concrete during mixing may create adhesion problems.

The barrier material should be compatible with the surface of the concrete.

Table 3.2-Repair methods for concrete surface defects

Description of concrete problems	Material	
	Name	Description
Small surface voids and rutted cracks	Portland cement grout ¹	1:1 grout, made with portland cement and sand passing the No. 30 sieve. Mixed to a creamy consistency.
	Epoxy, urethane, or resin latex with inert fillers	The latex or resin should have high filler content, blended to a thick consistency.
Large surface voids and rutted cracks	Dry-pack portland cement mortar ¹	1:2.5 to 1:3 mortar, made with portland cement, and sand passing a No. 16 sieve, mixed to a stiff consistency.
	Polymer (latex or epoxy) modified composition	Latex or epoxy with portland cement and suitable aggregates.
	Polymer (epoxy or acrylic) concrete	Epoxy or acrylic resins with suitable aggregates.
	Concrete	Normal mixes proportioned as in ACI 211.
	Shotcrete ⁽⁹⁾	Pneumatically applied concrete.
Holes: repair in confined area	Hydraulic cement and aluminum or iron powder with oxidizing agent	Proprietary mixes.
	Expansive portland cement compositions	ACI 223-Type K with suitable aggregates.

¹ Proprietary cementitious materials are available.

3.2-Repair of surface defects

ACI Committee 301 has developed procedures for the repair of surface defects in cast-in-place concrete, and these are described in this section.¹ For additional information review the procedures developed by the Bureau of Reclamation.⁴ Precast concrete is normally produced in a shop operation. Sharp offsets between precast sections should be corrected as indicated for new cast-in-place concrete. Surface defects, including tie holes, unless otherwise specified by the contract documents, should be repaired immediately after form removal (see Table 3.2).

3.2.1 Removal and repair of defects-Procedure-All honeycombed and defective concrete areas should be removed down to sound concrete. If chipping is necessary, the edges should be perpendicular to the surface or slightly undercut. No feathered edges should be permitted. The area to be patched and a band at least 6 in. (150 mm) wide surrounding it should be dampened to prevent absorption of water from the patching mortar. A bonding grout or bond coat should be prepared using a mix of approximately one part cement to one part fine sand (sand passing a No. 30 mesh sieve), mixed to a consistency of thick cream, and should then be well brushed into the surface. ACI 546.1R and ACI 303 also describe patching with portland cement concrete.^{13,14}

3.2.1.1 Patching material-The patching mixture should be made from the same materials and with approximately the same proportions used for the concrete if esthetics are important. The coarse aggregate should be omitted. The mortar should consist of no more than one part cement to 2 ½ parts sand by damp loose volume. Where appropriate, trial

patches with white portland cement replacing part of the gray portland cement should be made on exposed concrete to select the patch proportions with the best color match. The quantity of mixing water should be limited to that necessary for handling and placing. The patching mortar should be thoroughly mixed and worked with a trowel to the extent that it is the stiffest consistency that will permit placing.

3.2.1.2 Application of patching material-After surface water has evaporated from the area to be patched, the bond coat should be well brushed into the surface. When the bond coat begins to lose the water sheen, the premixed patching mortar should be applied. The mortar should be thoroughly consolidated into place and struck off so as to leave the patch slightly higher than the surrounding surface. To allow for some initial shrinkage, it should be left undisturbed for at least 1 hour before being finally finished. The patched area should be kept damp for 7 days. Metal tools should not be used in finishing a patch in a formed wall which will be exposed.

3.2.1.3 Special patching procedures for protective barriers-The repair of defects in concrete which will be covered with a protective barrier system for intermediate service (see Table 6.3) requires special attention. Conventional portland cement-based patching materials should not be used unless specifically recommended by the barrier material manufacturer. Adhesion of these patching materials to cured concrete may not be high enough to prevent loss of bond caused by the internal stresses in the barrier material (see Sections 6.1 and 6.2 for a more detailed explanation of this phenomenon) and use of proprietary patching materials with polymer addi-

tions should improve adhesion to the concrete, but it must be determined whether the polymer addition will affect the adhesion between the patching and barrier materials. Patching with resin-based materials, using the same resin that is used for the protective barrier material, may be the most reliable method. However, it is necessary to obtain specific recommendations from the manufacturer.

3.2.2 Tie holes—After being cleaned and thoroughly dampened, tie holes should be completely filled with patching mortar.

3.2.3 Proprietary materials—Proprietary compounds may be used in lieu of, or in addition to, the foregoing patching procedures.¹⁰ Such compounds must be used in accordance with the manufacturer's recommendations. Specific approval from the barrier manufacturer should be obtained before proprietary compounds are used for patching. These materials should be compatible with the barrier system and not interfere with good adhesion between the two.

3.2.4 Fins and sharp offsets—Fins, protrusions or similar irregularities projecting from the concrete surface should be removed back to the surface by chipping, bushhammering, needlegunning, or wire brushing. Care should be exercised to obtain a reasonably planar surface for application of the barrier system. Sharp offsets in the surface, such as those caused by formwork misalignment, should be mechanically abraded to provide gradual and smooth transitions between the offset surfaces. For some barrier systems, it is normally not necessary to have all surfaces of a concrete area in exactly the same plane, so long as the transitions are gradual and smooth. The barrier material manufacturer should be contacted for recommendations.

3.3-Stopping or rerouting of water

Water, seeping or flowing into or through a concrete structure must be stopped before a barrier system can be applied. Before deciding upon a repair procedure to stop the water, the type of defects present in the concrete and source of the water should be determined. Three options to solving this problem are:

1. Stop or reroute water at its source.
2. Stop water on surface opposite source.
3. Reroute water on surface opposite source.

3.3.1 Stopping or rerouting water at source—Excavation outside the structure and installation of new drainage should be considered. Submarine locations, bedrock, or abutting buildings may make excavation impossible or uneconomical. However, partial treatment to reduce flow of water from the water-source side may facilitate work on the opposite side.

3.3.2 Stopping water on surface not in contact with the source—When water is coming through a crack, hole, or porous area because the water cannot be stopped or rerouted at its source, it may be possible to stop the flow from the side opposite the water.

The use of cementitious quick-setting materials should be considered as water stops only until permanent surface repairs can be made. Epoxy injection or chemical grouts can be either a temporary or permanent repair depending on the following conditions. If the crack is nonmoving, epoxy injection could be a permanent repair. If cracks move enough to destroy adhesion between the concrete and the epoxy, the repair should be considered to be temporary. Chemical grout can be effective on a permanent basis if it is not allowed to dry out.

3.3.2.1 Cementitious quick-setting materials—These materials are made from portland cement, sand (in some cases) and a chemical that will accelerate the setting time or hardening. If metals (reinforcement, conduits, etc.) are embedded in the concrete of the structure being treated, materials containing chloride should not be used that would produce in the quick-setting mix a chloride ion content exceeding the limits suggested in Section 4.5.4 of the ACI 201 "Guide to Durable Concrete" for the various construction and environmental conditions described therein. Setting time may be from 15 seconds to several minutes, depending on the formulation used, mix proportions and temperature. Because of the alkaline nature of these materials, rubber gloves, goggles and protective clothing should be worn. Mixtures of plaster of paris and cement should not be used because of the danger of excessive expansion that could cause cracking of the patching material.

All loose and weakened concrete should be removed and the sides of a crack should be under-cut before patching proceeds. Detailed instructions concerning surface preparation, type of quick-setting materials, and mixing and application procedures should be obtained from the manufacturer of the quick-setting materials.

3.3.2.2 Epoxy injection—Temporarily seal the crack at the surface, using an epoxy resin paste, to withstand injection pressures. A low viscosity epoxy adhesive is then injected under pressure through ports which have been established in the surface seal. The injected adhesive displaces the water in the crack and after curing binds both faces of the crack to form a seal. Qualified and experienced applicators should be used for this work.

3.3.2.3 Chemical grouts—Small grout holes up to 1 in. (25 mm) diameter are drilled through the concrete wall in the area of the leaks. Pipes are inserted and a low viscosity (2 cps), 2-part plastic monomer solution is pumped into the soil. The soil becomes saturated with monomer which hardens to form a seal. The use of chemical grouts require qualified and experienced applicators and should be limited to special applications.

3.3.3 Rerouting water on surface not in contact with the source—Each crack through which water is flowing should be covered with a small hollow enclosure to form a channel. As an example, wire mesh formed in a semicircle is placed over the crack and a