

Deterioration of Concrete

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Chapter 3 Causes of Distress and Deterioration of Concrete

3-1. Introduction

General. Once the evaluation phase has been a completed for a structure, the next step is to establish the cause or causes for the damage that has been detected. Since many of the symptoms may be caused by more than one mechanism acting upon the concrete, it is necessary to have an understanding of the basic underlying causes of damage and deterioration. This chapter presents information on the common causes of problems in concrete. These causes are shown in Table 3-1. Items shown in the table are discussed in the subsequent sections of this chapter with the following given for each: (1) brief discussion of the basic mechanism; (2) description of the most typical symptoms, both those that would be observed during a visual examination and those that would be seen during a laboratory evaluation; and (3) recommendations for preventing further damage to new or replacement concrete. The last section of the chapter presents a logical method for relating the symptoms or observations to the various causes.

b. Approach to evaluation. Deterioration of concrete is an extremely complex subject. It would be simplistic to suggest that it will be possible to identify a specific, single cause of deterioration for every symptom detected during an evaluation of a structure. In most cases, the damage detected will be the result of more than one mechanism. For example, corrosion of reinforcing steel may open cracks that allow moisture greater access to the interior of the concrete. This moisture could lead to additional damage by freezing and thawing. In spite of the complexity of several causes working simultaneously, given a basic understanding of the various damagecausing mechanisms, it should be possible, in most cases, to determine the primary cause or causes of the damage seen on a particular structure and to make intelligent choices concerning selection of repair materials and methods.

3-2. Causes of Distress and Deterioration

a. Accidental loadings.

(1) Mechanism. Accidental loadings may be characterized as short-duration, one-time events such as the impact of a barge against a lock wall or an earthquake.

Table 3-1

Causes of Distress and Deterioration of Concrete
Accidental Loadings
Chemical Reactions
Acid attack
Aggressive-water attack
Alkali-carbonate rock reaction
Alkali-silica reaction
Miscellaneous chemical attack
Sulfate attack
Construction Errors
Corrosion of Embedded Metals
Design Errors
Inadequate structural design
Poor design details
Erosion
Abrasion
Cavitation
Freezing and Thawing
Settlement and Movement
Shrinkage
Plastic
Drying
Temperature Changes
Internally generated
Externally generated
Fire Weathering

These loadings can generate stresses higher than the strength of the concrete, resulting in localized or general failure. Determination of whether accidental loading caused damage to the concrete will require knowledge of the events preceding discovery of the damage. Usually, damage caused by accidental loading will be easy to diagnose.

(2) Symptoms. Visual examination will usually show spalling or cracking of concrete which has been subjected to accidental loadings. Laboratory analysis is generally not necessary.

(3) Prevention. Accidental loadings by their very nature cannot be prevented. Minimizing the effects of some occurrences by following proper design procedures (an example is the design for earthquakes) or by proper



attention to detailing (wall armor in areas of likely impact) will reduce the impacts of accidental loadings.

b. Chemical reactions. This category includes several specific causes of deterioration that exhibit a wide variety of symptoms. In general, deleterious chemical reactions may be classified as those that occur as the result of external chemicals attacking the concrete (acid attack, aggressive water attack, miscellaneous chemical attack, and sulfate attack) or those that occur as a result of internal chemical reactions between the constituents of the concrete (alkali-silica and alkali-carbonate rock reactions). Each of these chemical reactions is described below.

(1) Acid attack.

(a) Mechanism. Portland-cement concrete is a highly alkaline material and is not very resistant to attack by acids. The deterioration of concrete by acids is primarily the result of a reaction between the acid and the products of the hydration of cement. Calcium silicate hydrate may be attacked if highly concentrated acid exists in the environment of the concrete structures. In most cases, the chemical reaction results in the formation of water-soluble calcium compounds that are then leached away. In the case of sulfuric acid attack, additional or accelerated deterioration results because the calcium sulfate formed may affect the concrete by the sulfate attack mechanism (Section 3-2b(6)). If the acid is able to reach the reinforcing steel through cracks or pores in the concrete, corrosion of the reinforcing steel will result and will cause further deterioration of the concrete (ACI 201.2R).

(b) Symptoms. Visual examination will show disintegration of the concrete evidenced by loss of cement paste and aggregate from the matrix (Figure 2-13). If reinforcing steel has been reached by the acid, rust staining, cracking, and spalling may be present. If the nature of the solution in which the deteriorating concrete is located is unknown, laboratory analysis can be used to identify the specific acid involved.

(c) Prevention. A dense concrete with a low water-cement ratio (w/c) may provide an acceptable degree of protection against a mild acid attack. Portland-cement concrete, because of its composition, is unable to withstand attack by highly acidic solutions for long periods of time. Under such conditions, an appropriate surface coating or treatment may be necessary. ACI Committee 515 has extensive recommendations for such coatings (ACI 515.1R).

(2) Aggressive-water attack.

(a) Mechanism. Some waters have been reported to have extremely low concentrations of dissolved minerals. These soft or aggregative waters will leach calcium from cement paste or aggregates. This phenomenon has been infrequently reported in the United States. From the few cases that have been reported, there are indications that this attack takes place very slowly. For an aggressivewater attack to have a serious effect on hydraulic structures, the attack must occur in flowing water. This keeps a constant supply of aggressive water in contact with the concrete and washes away aggregate particles that become loosened as a result of leaching of the paste (Holland, Husbands, Buck, and Wong 1980).

(b) Symptoms. Visual examination will show concrete surfaces that are very rough in areas where the paste has been leached (Figure 2-12). Sand grains may be present on the surface of the concrete, making it resemble a coarse sandpaper. If the aggregate is susceptible to leaching, holes where the coarse aggregate has been dissolved will be evident. Water samples from structures where aggressive-water attack is suspected may be analyzed to calculate the Langlier Index, which is a measure of the aggressiveness of the water (Langlier 1936).

(c) Prevention. The aggressive nature of water at the site of a structure can be determined before construction or during a major rehabilitation. Additionally, the water-quality evaluation at many structures can be expanded to monitor the aggressiveness of water at the structure. If there are indications that the water is aggressive or is becoming aggressive, areas susceptible to high flows may be coated with a nonportland-cement-based coating.

(3) Alkali-carbonate rock reaction.

(a) Mechanism. Certain carbonate rock aggregates have been reactive in concrete. The results of these reactions have been characterized as ranging from beneficial to destructive. The destructive category is apparently limited to reactions with impure dolomitic aggregates and are a result of either dedolomitization or rim-silicification reactions. The mechanism of alkali-carbonate rock reaction is covered in detail in EM 1110-2-2000.

(b) Symptoms. Visual examination of those reactions that are serious enough to disrupt the concrete in a



structure will generally show map or pattern cracking and a general appearance which indicates that the concrete is swelling (Figure 2-7). A distinguishing feature which differentiates alkali-carbonate rock reaction from alkali-silica reaction is the lack of silica gel exudations at cracks (ACI 201.2R). Petrographic examination in accordance with ASTM C 295 (CRD-C 127) may be used to confirm the presence of alkali-carbonate rock reaction.

(c) Prevention. In general, the best prevention is to avoid using aggregates that are or suspected of being reactive. Appendix E of EM 1110-2-2000 prescribes procedures for testing rocks for reactivity and for minimizing effects when reactive aggregates must be used.

(4) Alkali-silica reaction.

(a) Mechanism. Some aggregates containing silica that is soluble in highly alkaline solutions may react to form a solid nonexpansive calcium-alkali-silica complex or an alkali-silica complex which can imbibe considerable amounts of water and then expand, disrupting the concrete. Additional details may be found in EM 1110-2-2000.

(b) Symptoms. Visual examination of those concrete structures that are affected will generally show map or pattern cracking and a general appearance that indicates that the concrete is swelling (Figure 2-6). Petrographic examination may be used to confirm the presence of alkali-silica reaction.

(c) Prevention. In general, the best prevention is to avoid using aggregates that are known or suspected to be reactive or to use a cement containing less than 0.60 percent alkalies (percent Na₂0 + (0.658) percent K₂0). Appendix D of EM 1110-2-2000 prescribes procedures for testing aggregates for reactivity and for minimizing the effects when reactive aggregates must be used.

(5) Miscellaneous chemical attack.

(a) Mechanism. Concrete will resist chemical attack to varying degrees, depending upon the exact nature of the chemical. ACI 515.1R includes an extensive listing of the resistance of concrete to various chemicals. To produce significant attack on concrete, most chemicals must be in solution that is above some minimum concentration. Concrete is seldom attacked by solid dry chemicals. Also, for maximum effect, the chemical solution needs to be circulated in contact with the concrete. Concrete subjected to aggressive solutions under positive differential pressure is particularly vulnerable. The pressure gradients tend to force the aggressive solutions into the matrix. If the low-pressure face of the concrete is exposed to evaporation, a concentration of salts tends to accumulate at that face, resulting in increased attack. In addition to the specific nature of the chemical involved, the degree to which concrete resists attack depends upon the temperature of the aggressive solution, the w/c of the concrete, the type of cement used (in some circumstances), the degree of consolidation of the concrete, the permeability of the concrete, the degree of wetting and drying of the chemical on the concrete, and the extent of chemically induced corrosion of the reinforcing steel (ACI 201.1R).

(b) Symptoms. Visual examination of concrete which has been subjected to chemical attack will usually show surface disintegration and spalling and the opening of joints and cracks. There may also be swelling and general disruption of the concrete mass. Coarse aggregate particles are generally more inert than the cement paste matrix; therefore, aggregate particles may be seen as protruding from the matrix. Laboratory analysis may be required to identify the unknown chemicals which are causing the damage.

(c) Prevention. Typically, dense concretes with low w/c (maximum w/c = 0.40) provide the greatest resistance. The best known method of providing long-term resistance is to provide a suitable coating as outlined in ACI 515.1R.

(6) Sulfate attack.

(a) Mechanism. Naturally occurring sulfates of sodium, potassium, calcium, or magnesium are sometimes found in soil or in solution in ground water adjacent to concrete structures. The sulfate ions in solution will attack the concrete. There are apparently two chemical reactions involved in sulfate attack on concrete. First, the sulfate reacts with free calcium hydroxide which is liberated during the hydration of the cement to form calcium sulfate (gypsum). Next, the gypsum combines with hydrated calcium aluminate to form calcium sulfoaluminate (ettringite). Both of these reactions result in an increase in volume. The second reaction is mainly responsible for most of the disruption caused by volume increase of the concrete (ACI 201.2R). In addition to the two chemical reactions, there may also be a purely physical phenomenon in which the growth of crystals of sulfate salts disrupts the concrete.

(b) Symptoms. Visual examination will show map and pattern cracking as well as a general disintegration of



the concrete (Figure 2-14). Laboratory analysis can verify the occurrence of the reactions described.

(c) Prevention. Protection against sulfate attack can generally be obtained by the following: Use of a dense, high-quality concrete with a low water-cement ratio; Use of either a Type V or a Type II cement, depending upon the anticipated severity of the exposure (EM 1110-2-2000); Use of a suitable pozzolan (some pozzolans, added as part of a blended cement or separately, have improved resistance, while others have hastened deterioration). If use of a pozzolan is anticipated, laboratory testing to verify the degree of improvement to be expected is recommended.

c. Construction errors. Failure to follow specified procedures and good practice or outright carelessness may lead to a number of conditions that may be grouped together as construction errors. Typically, most of these errors do not lead directly to failure or deterioration of concrete. Instead, they enhance the adverse impacts of other mechanisms identified in this chapter. Each error will be briefly described below along with preventative methods. In general, the best preventive measure is a thorough knowledge of what these construction errors are plus an aggressive inspection program. It should be noted that errors of the type described in this section are equally as likely to occur during repair or rehabilitation projects as they are likely to occur during new construction.

(1) Adding water to concrete. Water is usually added to concrete in one or both of the following circumstances: First, water is added to the concrete in a delivery truck to increase slump and decrease emplacement effort. This practice will generally lead to concrete with lowered strength and reduced durability. As the w/c of the concrete increases, the strength and durability will decrease. In the second case, water is commonly added during finishing of flatwork. This practice leads to scaling, crazing, and dusting of the concrete in service.

(2) Improper alignment of formwork. Improper alignment of the formwork will lead to discontinuities on the surface of the concrete. While these discontinuities are unsightly in all circumstances, their occurrence may be more critical in areas that are subjected to highvelocity flow of water, where cavitation-erosion may be induced, or in lock chambers where the "rubbing" surfaces must be straight.

(3) Improper consolidation. Improper consolidation of concrete may result in a variety of defects, the most common being bugholes, honeycombing, and cold joints.

"Bugholes" are formed when small pockets of air or water are trapped against the forms. A change in the mixture to make it less "sticky" or the use of small vibrators worked near the form has been used to help eliminate bugholes. Honeycombing can be reduced by inserting the vibrator more frequently, inserting the vibrator as close as possible to the form face without touching the form, and slower withdrawal of the vibrator. Obviously, any or all of these defects make it much easier for any damage-causing mechanism to initiate deterioration of the concrete. Frequently, a fear of "overconsolidation" is used to justify a lack of effort in consolidating concrete. Overconsolidation is usually defined as a situation in which the consolidation effort causes all of the coarse aggregate to settle to the bottom while the paste rises to the surface. If this situation occurs, it is reasonable to conclude that there is a problem of a poorly proportioned concrete rather than too much consolidation.

(4) Improper curing. Curing is probably the most abused aspect of the concrete construction process. Unless concrete is given adequate time to cure at a proper humidity and temperature, it will not develop the characteristics that are expected and that are necessary to provide durability. Symptoms of improperly cured concrete can include various types of cracking and surface disintegration. In extreme cases where poor curing leads to failure to achieve anticipated concrete strengths, structural cracking may occur.

(5) Improper location of reinforcing steel. This section refers to reinforcing steel that is improperly located or is not adequately secured in the proper location. Either of these faults may lead to two general types of problems. First, the steel may not function structurally as intended, resulting in structural cracking or failure. A particularly prevalent example is the placement of welded wire mesh in floor slabs. In many cases, the mesh ends up on the bottom of the slab which will subsequently crack because the steel is not in the proper location. The second type of problem stemming from improperly located or tied reinforcing steel is one of durability. The tendency seems to be for the steel to end up near the surface of the concrete. As the concrete cover over the steel is reduced, it is much easier for corrosion to begin.

(6) Movement of formwork. Movement of formwork during the period while the concrete is going from a fluid to a rigid material may induce cracking and separation within the concrete. A crack open to the surface will allow access of water to the interior of the concrete. An internal void may give rise to freezing or corrosion problems if the void becomes saturated.



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