



Concrete Distress and Deterioration - Symptoms and Causes

An Online Continuing Education Course for Engineers

Course Number: C-2006

Credit: 2 Hours / 2 PDH / 2 CPD

CAUSES OF DISTRESS AND DETERIORATION OF CONCRETE

INTRODUCTION

General. Many of the symptoms of concrete damage may be caused by more than one mechanism acting upon the concrete, so it is necessary to have an understanding of the basic underlying causes of distress and deterioration. This course presents information on the common causes of problems in concrete. These causes are shown in Table 1. Items shown in the table are discussed in the subsequent sections of this course 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 course presents a logical method for relating the symptoms or observations to the various causes.

Approach to evaluation. Deterioration of concrete is an extremely complex subject. It would be simplistic to suggest that it is 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 damage-causing 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.

Table 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

CAUSES OF DISTRESS AND DETERIORATION

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.

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.

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.

Acid Attack

1. 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 (See “sulfate attack” below). 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.
2. Symptoms. Visual examination will show disintegration of the concrete evidenced by loss of cement paste and aggregate from the matrix. 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.
3. 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

THE DETERIORATION OF CONCRETE BY ACIDS IS PRIMARILY THE RESULT OF A REACTION BETWEEN THE ACID AND THE PRODUCTS OF THE HYDRATION OF CEMENT.

THE AGGRESSIVE NATURE OF WATER AT THE SITE OF A STRUCTURE CAN BE DETERMINED BEFORE CONSTRUCTION OR DURING A MAJOR REHABILITATION.

to withstand attack by highly acidic solutions for long periods of time. Under such conditions, an appropriate surface coating or treatment may be necessary.

Aggressive-Water Attack

1. Mechanism. Some waters have been reported to have extremely low concentrations of dissolved minerals. These soft or aggressive 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 aggressive-water 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.
2. Symptoms. Visual examination will show concrete surfaces that are very rough in areas where the paste has been leached. 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.
3. 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.

Alkali-Carbonate Rock Reaction

1. 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.
2. 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. A distinguishing feature which differentiates alkali-carbonate rock reaction from alkali-silica reaction is the lack of silica gel exudations at cracks. Petrographic examination in accordance with ASTM International's *Standard Guide for Petrographic Examination of Aggregates for Concrete* (ASTM C 295/C295M-11) may be used to confirm the presence of alkali-carbonate rock reaction.
3. Prevention. In general, the best prevention is to avoid using aggregates that are, or are suspected of being, reactive.



CONCRETE WILL RESIST CHEMICAL ATTACK TO VARYING DEGREES, DEPENDING UPON THE EXACT NATURE OF THE CHEMICAL.

Alkali-Silica Reaction

1. 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.
2. 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. Petrographic examination may be used to confirm the presence of alkali-silica reaction.
3. 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 alkalis (percent $\text{Na}_2\text{O} + (0.658)$ percent K_2O).

Miscellaneous Chemical Attack

1. Mechanism. Concrete will resist chemical attack to varying degrees, depending upon the exact nature of the chemical. 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.
2. 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

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.

cement paste matrix.

3. For

Sulfate

1. Mechanisms of sulfate attack in solution of concrete are applied in various ways. First, the hydroxyl ions hydrate sulfate (forming a combination of sulfate and water) in an ettringite reaction. This causes the disruption of the concrete. 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.
2. Symptoms. Visual examination will show map and pattern cracking as well as a general disintegration of the concrete. Laboratory

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...ative 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