PDHonline Course S155 (1 PDH)

Concrete Deterioration

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2020

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Concrete Deterioration

Reinforced concrete is a very versatile construction material. Properly designed concrete structures are both strong and durable. However, concrete structures are vulnerable to a number of factors that can cause deterioration. Deterioration can result in loss of strength and unsafe conditions. Therefore it is important to have an understanding of the vulnerabilities of concrete structures in order to help minimize long-term repair and maintenance costs.

Source: Interiors & Sources

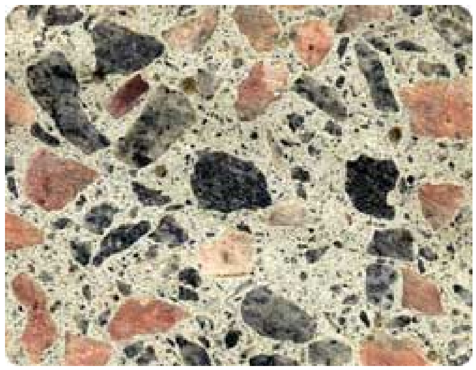
Concrete Basics

Concrete consists of three basic ingredients; Portland cement, aggregates (both fine/sand and coarse/stone) and water. The ingredients are mixed to form a flowable mixture that can be placed in forms that mold the concrete into the desired shape. After the concrete ingredients are mixed, the Portland cement begins to hydrate. This process involves the chemical bonding of the cement with the water molecules, which will eventually form a hardened matrix.

Source: Concrete Network

Hardened concrete has very good compressive strength, but very poor tensile strength. Concrete tensile strength is about 10% of its compressive strength. Steel on the other hand has both very good tensile strength and thermal properties that are compatible with concrete. The complementary properties of concrete and steel are combined to provide reinforced concrete structures that are capable of supporting considerable loads.

Concrete is also highly alkaline. This property provides an environment that limits the corrosion of any embedded steel and helps to assure the durability of the reinforced concrete member. For this reason reinforcing bars are embedded well below the concrete surface. The required cover typically ranges from 1½ to 3 inches, depending on the type of environmental exposure. Unfortunately, maintaining proper cover during construction is difficult. Consequently insufficient cover is a common occurrence. The closer steel is to the concrete surface, the more likely it will corrode.



Source: Volumetric Mixer Manufacturers Bureau

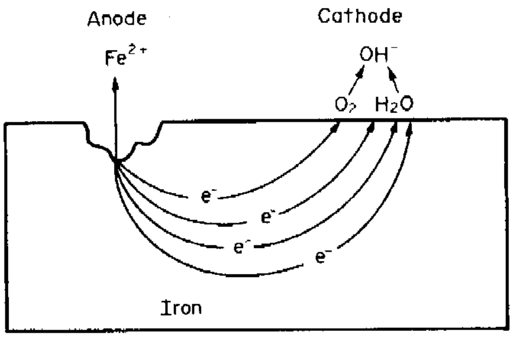
Concrete deterioration typically occurs when the material is exposed to weather, water or chemicals over an extended period of time. When protected from these elements, as in the case of internal members of enclosed commercial and institutional buildings, reinforced concrete can be expected to perform for decades with very little maintenance. However, in many cases, concrete can be exposed to environments that promote deterioration. Examples of these types of environments include parking garages, exterior balcony slabs, and industrial structures where the concrete is exposed to process chemicals. Long-term deterioration can occur at the embedded reinforcing steel as well as at the exposed concrete surface.

Source: City of Lincoln, Nebraska

The useful service life of a concrete structure is typically a function of the corrosion rate of the reinforcement. Before this corrosion can start, aggressive elements such as chlorides or carbon dioxide must penetrate the concrete in sufficiently high concentrations, to the depth of the embedded reinforcing steel. Corrosion of steel is an expansive process. The process fractures the surrounding concrete and weakens the steel as it rusts. Concrete can also deteriorate because of chemical reactions between and within the cement matrix, aggregate and moisture.

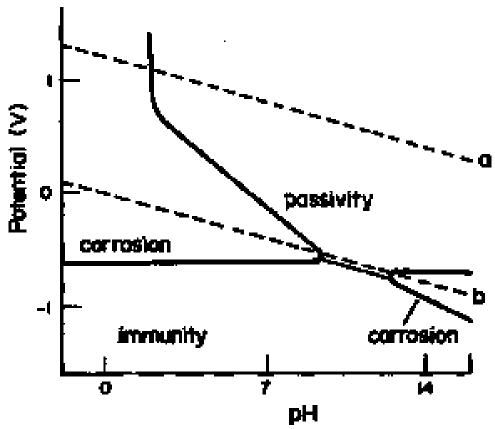
Corrosion

Corrosion of reinforcing can be simplified into two processes, anodic and cathodic. The anodic process is the dissolution of iron atoms to ferrous ions when the protective layer at the surface of the reinforcement has been destroyed. The cathodic process involves the reduction of oxygen as it reacts with water to form hydroxyl ions. The anode and cathode are separated by distances that can vary greatly. The anode and cathode areas may alternate along a continuous reinforcing steel bar when areas of the bar become anodic and adjacent areas become cathodic. Oxygen is only required at the cathode to remove electrons from the bar that were liberated from the oxidation of the iron.



Source: Case Western Reserve University

Concrete is a porous material. Carbon dioxide in the air will penetrate to the interior of the concrete via its pores. Calcium hydroxide together with the soluble alkalies in the cement, gives concrete a pH of about 12.5. Carbonation results when carbon dioxide reacts with the calcium hydroxide, which in turn causes a decrease in the pH of the concrete. The carbonation process starts at the surface and penetrates slowly to the interior of the concrete. The diffusion of carbon dioxide follows air-filled pores. Therefore totally water-saturated concrete, as is the case with below grade and marine structures, will not carbonate.



Source: Case Western Reserve University

Reinforcing steel in concrete is protected against corrosion because the alkalinity of the concrete allows the steel to form a protective layer that prevents the anodic dissolution of the iron. If carbonation of the concrete causes a drop in the normal pH level of the matrix below a threshold level, or if the chloride content of the concrete at the reinforcing exceeds a critical value, then the protective layer around the steel will dissolve and deterioration in the form of corrosion of the steel will start. In both cases, however, the presence of moisture is necessary to perpetuate the deterioration process.

Source: Lake Worth Media

Chloride ions from road deicers may penetrate via the pores to the interior of the concrete. While carbon dioxide needs air-filled pores for penetration, chloride spreads by diffusion through totally or partly water-filled pores. The wetting and drying of a concrete surface with chloride containing water will cause a high concentration of chloride at the surface. Due to the diffusion process, the chloride concentration will normally decrease between the surface and the interior of the concrete. In structures containing cracks, both carbonation and chlorides tend to penetrate faster towards the embedded reinforcing. Narrow cracks can limit the amount of penetration, but wider cracks often have a high chloride concentration at the root of the crack in the region of the reinforcing.

Source: Cefracor

Chlorides may be introduced into concrete from a variety of sources. Natural aggregates are a common source of trace levels, but may also contain as much as 0.19 percent chloride or more by weight of aggregate, particularly in desert or coastal regions. Another source of chlorides is the mixing water. If the aggregate is salt contaminated or if chlorides containing admixtures are used to mix the concrete, accelerated corrosion of the embedded reinforcing steel can occur. By far the most common source of destructive chloride for concrete structures in the northern United States is deicing salt. Both calcium chloride and sodium chloride are applied to streets and bridge decks to prevent snow and ice buildup. Seawater, the next most obvious source, is not always as aggressive due to the presence of magnesium sulfate salts. The magnesium sulfate acts together with sodium chloride to clog the surface pores of the concrete slowing the diffusion rate. It is recommended, however, that Type II (sulfate resistant cement) be used in seawater conditions and soils that contain sulfates for reasons described below under sulfate attack. It has only been in recent years that the addition of chloride has been discouraged in reinforced concrete. Calcium chloride was first used as set accelerator in the late 1980s. The addition of 1 to 2 percent by weight of cement of calcium chloride as a set accelerator was common in winter concreting. Its use has been discouraged in reinforced concrete due to its accelerating effect on the corrosion of reinforcing steel.

Source: Riversides

Freeze/Thaw Damage

Wet concrete and freezing conditions are a bad combination. Water expands when it freezes. If trapped in concrete, it creates outward pressure on the surrounding material. Concrete subjected to freeze/thaw cycles is typically air-entrained by adding a chemical admixture to the concrete. Air-entraining admixtures cause microscopic air bubbles to form throughout the cement matrix. The resulting air bubbles provide space to accommodate the expansion of freezing water.

Freeze/thaw damage generally occurs in two forms. The first is common to open parking decks and other horizontal surfaces that collect standing water. Freeze/thaw cycles gradually deteriorate the concrete surface, exposing aggregate and leaving the concrete with an eroded appearance. As the surface breaks down, it becomes more porous, which in turn promotes even further deterioration.

Source: National Research Council Canada

The second form of freeze/thaw damage is associated with water freezing in cracks. A larger concentration of water can collect in a crack than in a naturally occurring surface pores. Consequently, the resulting damage typically occurs more quickly and severely. Cracks also allow water to penetrate directly to reinforcing steel. This may initiate or accelerate corrosion and other moisture-related forms of deterioration.

Source: Roberts-Seymour Consulting

Alkali-Silica Reaction, Delayed Ettringite Formation, Sulfate Attack and Alkali-Carbonate Reaction

Referred to as ASR and DEF, alkali-silica reaction and delayed ettringite formations are both chemical reactions caused by properties of the aggregate and cement, respectively. DEF is sometimes called an internal sulfate attack. An external source of sulfur is not required for this type of deterioration to occur. Sulfate attack also involves ettringite formation, but it occurs because of a different process. Although the reactions are different, the effect is similar; a crystalline or gel-like substance forms within the hardened concrete, causing it to expand and crack. The alkali carbonate reaction (ACR) relates to faulty calcite and dolomite aggregates that perform poorly when placed in the alkaline environment of Portland cement concrete. All of the above reactions are catalyzed by moisture, and gradually progress into the concrete as cracking allows deeper water penetration.

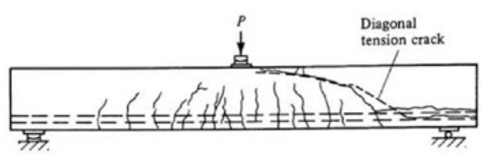
ASR Cracking

DEF Cracking

Source: FHWA

Other Forms of Concrete Duress

Distress of concrete can also be caused by overloading or under design of a structural member. In both cases, the structure is incapable of supporting the imposed loads. In extreme cases, collapse can occur. More often, early warning signs appear in the form of excess deflection or critically configured cracks.



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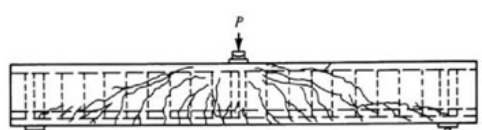


(b)

Source: HIS GlobalSpec

Fire can cause severe concrete damage because of shock heating. Concrete expands as it's heated. In the extreme heat of a fire, the outer layer will expand much more quickly than the inner portion, causing it to fracture and break away. This type of damage can also occur in reverse when the fire is doused by fire hoses or a sprinkler system. In this case, hot concrete is cooled suddenly, causing the outer layer to shrink and break away.

Source: Jeremy P. Ingham

Lightning damage to concrete is also caused by differential thermal heating. In this case, however, the heating is caused when extreme concentrations of electrical voltage are forced through the concrete. The concrete will conduct the electricity, but heats up as the energy is emitted as heat. Lightning is generally attracted to the embedded reinforcing steel. Once lightning enters the reinforcing steel, it won't stop until it reaches a ground. Because steel is an excellent conductor, the voltage tends to be transmitted through the reinforcing cage, but will arc through concrete at discontinuities. Consequently, an electrically continuous reinforcing cage minimizes damage because at discontinuities, explosive spalls are likely to occur. Also, if reinforcing steel is heated sufficiently, it will expand and may crack the surrounding concrete.

Source: All-Lines Public Adjusters

Condition Evaluations

A thorough investigation of existing deterioration must be performed before developing an effective repair and maintenance program. An engineering firm specializing in the evaluation and repair of existing structures should perform the investigation. A comprehensive investigation includes on-site surveys and testing that is accompanied by laboratory materials studies.

The first step in an investigation of concrete deterioration is a visual condition survey. This involves detailed observation and documentation of the structure's condition, with attention paid to the structural system and modifications, it's intended and actual use, typical and anomalous conditions and a brief survey of the structure's environment. Based on the findings of the visual survey, a testing and analysis program should be developed. This program may involve a variety of non-destructive and destructive techniques.

Source: FHWA

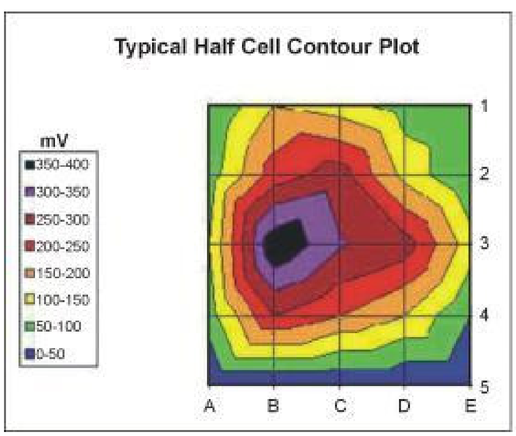
The most common method for evaluating near-surface concrete deterioration involves dragging a steel chain across the surface of a slab. When it's dragged across good concrete, a relatively high-pitched sound is emitted. However, concrete with sub-surface deterioration produces a distinctly lower-pitched, "hollow" sound. This low-tech method can be an effective means of evaluating the extent of sub-surface concrete deterioration. At vertical and overhead locations, a metal hammer or plastic mallet can be used in lieu of a chain similar to that illustrated in the previous slide.

Source: FHWA

A visual condition survey will likely identify areas of potentially hidden deterioration. In the case of a parking structure, this may include a waterproofing membrane below a topping slab, connections between structural elements or portions of the structure hidden behind partitions and finishes. At such locations, small openings should be made to allow direct observation of hidden elements. A fiber-optic scope can often permit observations of hidden conditions with only very small probe holes. The size and configuration of embedded reinforcing steel sometimes needs to be evaluated. This can be accomplished with a combination of specialized metal detectors and probe openings. In some cases, ground-penetrating radar and X-ray technology can also be useful for evaluation.

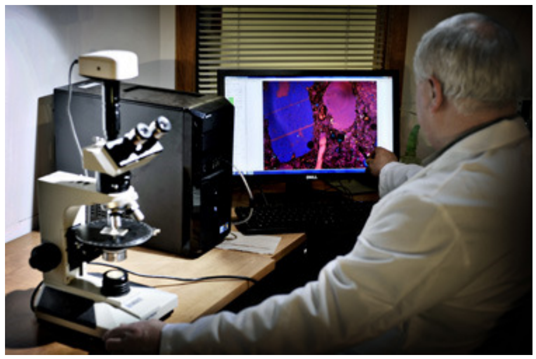
Source: Davis Laboratories, Inc.

Reinforcing steel corrosion is both an electrical and a chemical process. It produces low-level voltage similar to a battery. Half-cell testing involves setting up an electrical circuit that can be connected to reinforcing steel at regular intervals, usually on a grid. Electrical potential (voltage) is measured at the grid points. A high potential correlates to a high risk of corrosion. Half-cell testing is an effective means of identifying parts of a structure most vulnerable to steel corrosion.



Source: Federal Lands Highway Program

Material testing can be the most critical part of an investigation. A variety of testing methods are available to complement information gathered in the field. For concrete structures, the first step is extraction of core samples. Common tests performed on core samples include compressive strength, depth of carbonation and chloride content. Other tests include microscopic (or petrographic) and chemical studies to evaluate specimen composition and condition in detail. A well-designed testing regimen is an important tool for the development of appropriate repair recommendations. Occasionally, areas of structural concern are identified during an investigation. I n such cases, a structural analysis may be required to evaluate the need for strengthening of the affected members. Structural drawings should be reviewed as part of the analysis, if available.



Source: Schmitt Technical Services

Repair, Protection and Strengthening

During the past thirty years, concrete repair and protection techniques have been increasingly standardized, and there are many contractors who specialize in this type of work. It's important to note the difference between repairing a structure and protecting it from future deterioration.

Concrete repair generally involves removing deteriorated concrete, cleaning and preparing the repair cavity and reinforcing steel, and placing new concrete. To assure a sound repair, the repair cavity needs to be carefully shaped and prepared. The repair material must be carefully selected, placed and cured. Repair documents should include both drawings and written specifications and be prepared by a qualified engineering firm. Repairs should be executed by a specialty contractor experienced in concrete repair.

Source: JR Radlinger

Once the concrete has been repaired, it's important to protect the structure from continued deterioration. Concrete protection almost always involves limiting the amount of moisture that can reach the concrete. This can usually be achieved through a combination of drainage improvements and coatings. Installing additional drains and re-grading areas with poor drainage can help prevent moisture-related damage. Waterproofing coatings provide direct protection against moisture. However, improper coating application can actually increase deterioration by trapping moisture inside of the concrete. An effective protection program should be based on a thorough review of the existing structure.

Source: Crom Engineering and Construction Services

In addition to repair and protection, some structures require strengthening. A variety of materials and systems are available for strengthening almost any structural concrete component. Supplemental steel and concrete elements are often employed. Other materials used include carbon fiber sheets and glass fiber reinforced plastic (GFRP) structural members.

Source: Schnell Contractors, Inc