Deterioration of indoor parking garages

Litvan, G. G.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000757
Canadian Building Digest, 1982-07-01

Canadian Building Digest
Division of Building Research, National Research Council Canada

CBD-224

Deterioration of Indoor Parking Garages

Please note

This publication is a part of a discontinued series and is archived here as an historical reference. Readers should consult design and regulatory experts for guidance on the applicability of the information to current construction practice.

Originally published July 1982.

G.G. Litvan

Deterioration of indoor parking garages has become a very serious problem in recent years; major repairs are needed, in many cases, even after five years of service. Lacking a nationwide survey of the damages, the total cost of repairs in Canada is not known, but is estimated to be in excess of 1.5 billion dollars. Restoration can sometimes cost more than the original construction. This Digest describes the causes of rapid deterioration of parking decks and the guidelines that should be followed to achieve good durability.

Corrosion of the Reinforcing Steel

The cause of the deterioration of parking garages is usually corrosion of the reinforcing steel due to the action of de-icing salts carried in by vehicles. Frost action seldom occurs because the temperature, even in unheated garages, usually remains above the freezing point.

Corrosion is an electrochemical process which can best be understood by the description of a simple electrochemical cell (Figure 1). This cell consists of two electrodes, in this case iron and copper, immersed in water and connected to each other.

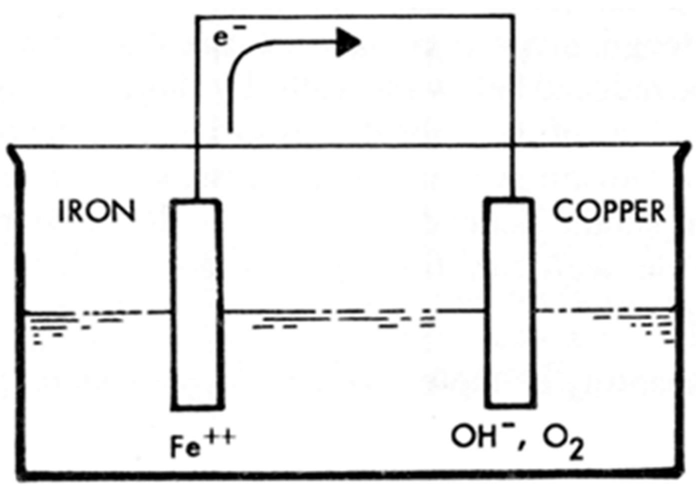

Figure 1. Schematic diagram of galvanic cell.

Iron has a tendency, in the presence of a liquid, to revert to its stable state, iron oxide. In the first step of the process, called anode reaction, the iron dissolves by conversion of the metallic iron into positively charged iron ions while liberating two electrons. Because electrons cannot exist on their own in large numbers, they have to be consumed in a simultaneous complementary reaction at the other electrode, called the cathode. In the presence of oxygen and water, this reaction produces hydroxyl ions which, with the ferrous ions, form a precipitate consisting of ferrous hydroxide. If exposed to oxygen, this is converted to ferric hydroxide, the familiar reddish brown rust. Thus, the essential elements for this galvanic cell to function are: the anode where the corrosion takes place; the cathode which does not corrode, but maintains ionic balance necessary for the corrosion to proceed; the electrolyte to conduct electric current; and oxygen.

In concrete the reinforcing steel is not perfectly uniform; variations exist in its composition, the level of stress, or the nature of its immediate environment. These factors affect the tendency of iron to revert to a combined state so that one part of the steel will act as anode and another as cathode. If moisture and oxygen are available, the galvanic cell will operate as described which will result in the conversion of steel into rust.

In uncontaminated concrete, steel is protected from corrosion by the presence of lime which creates a strong alkaline environment (pH = 12-13). Under these circumstances the steel behaves as a nobler metal, which has no tendency to dissolve, and develops "passivity". This resistance to corrosion exists as long as the lime is not neutralized by carbonation, which lowers the pH below the critical value of about 11.8. Soluble chlorides, however, can destroy the passivity of steel even when the pH is high. Despite extensive studies, the mechanism by which chlorides promote corrosion is still not well understood. Unfortunately, chlorides are not consumed in the process, but act as a catalyst. Because the effect of chlorides on the corrosion activity is proportional to the concentration, it should be kept as low as possible. The threshold value of chloride content, above which passivity of the reinforcing steel is destroyed, is 0.20% of total chloride ions by weight of cement.

Cracks in the concrete may form because the iron oxide corrosion products occupy a larger volume that the original metal. In addition, debonding of the steel may lead to breakdown of the matrix.

Protection of Embedded Steel from Corrosion

It is clear, therefore, that corrosion in concrete can be stopped if one of the essential elements (steel, oxygen, water, chloride) is unavailable for the galvanic process.

Creating electric discontinuity

If steel is coated with an electrical-insulating material the electrochemical process cannot proceed; this is of great practical importance. Of the numerous materials, powder-epoxy has been found to be the best coating. A thin coat (approximately 0.2 mm) is impervious, sufficiently flexible, and bonds well to concrete and reinforcing steel so that damage during transportation, bending and installation can be kept at an acceptable level. Epoxy-coated rebars have performed well in concrete used in bridge decks and should be useful for parking garage floors. The added cost has to date limited its use for this application but it could be considered in critical cases.

Exclusion of reactants

Corrosion of the steel can also be avoided by preventing water, oxygen and, most important, chlorides from entering the concrete. Several measures can be taken either singly or in combination, to minimize the ingress of these chemicals.

Design -- Obviously, if water does not accumulate on the surface of concrete the problem of influx may not even arise. For good drainage a minimum of 2 cm per 1 m length slope is considered essential, and should not be reduced below this value by short- or long-term deflections of the slabs due to shrinkage, creep, thermal or moisture variations. The distance between floor drains should not exceed 18 metres. It is important to provide well-functioning and durable expansion joints.

Concrete -- Because good quality concrete has low permeability and low porosity, 35 MPa high-strength concrete with low slump (50 mm) should be specified and good compaction assured.

Air entrainment (5 to 6%) facilitates compaction by increasing workability and is therefore desirable. To achieve the required quality, seven days of wet curing is recommended.

Cover -- In order to protect the steel from moisture, the reinforcement has to be covered at the top with at least 50 mm and at the underside with 25 mm thick concrete. To achieve uniform coverage the reinforcing steel network has to be carefully aligned and support chairs for top and bottom reinforcing steel should be provided at intervals not exceeding 1 m.

The importance of adequate concrete cover cannot be overemphasized. Increasing the thickness of the concrete from 5 to 10 cm will reduce the rate of migration toward the steel by 75%. Substantial cover is also beneficial as the concentration of chloride ions reaching the rebar is reduced by the interaction of cement components with chlorides. Also, the undesirable penetration of carbon dioxide, which by reacting with lime, reduces the alkalinity of concrete, is retarded by a thicker concrete layer. In this respect the use of blended cement containing slag is advantageous because it has low permeability and helps to maintain high pH. For the protection of the steel there are other means of waterproofing concrete which could be utilized in conjunction with adequate concrete cover.

Membranes -- A good quality membrane, properly installed on the concrete surface, extends the life of parking decks significantly. Protection appears to be achieved even when it is placed over contaminated concrete. The large number of waterproofing systems offered commercially makes selection of the most suitable system very difficult, and evaluations by authorities become rapidly obsolete due to changes in technology and the market place. Selection of a waterproofing membrane should be based on proven performance in the geographic area of the intended application and, because of the importance of workmanship, a reliable contractor should be chosen.

Waterproofing membranes can be preformed or applied-in-place. Due to controlled manufacturing conditions, the thickness and other properties of preformed membranes are uniform and of specified value. On the other hand, the weakness of this system is that skill is required in application, particularly on surfaces with irregular features. Drains, laps and expansion joints are always potential problem spots. The applied-in-place products are easily installed, regardless of the geometry, and are well bonded to the substrate, but great care has to be exercised to achieve uniform thickness and to prevent pinholes.

Waterproofers may be plastic or elastomeric based, such as epoxy, polyurethane, rubberized asphalt, coal tar, chlorinated rubber, neoprene, etc. The integrity of the membrane is protected from abrasion by another layer called wearing course. Unfortunately, such a cover may trap brine on the surface of the membrane and thus increase the probability of liquid ingress if a discontinuity in the waterproofer exists. Such a deficiency of the membrane becomes noticeable only after the deterioration is fairly serious. Another disadvantage of the membrane is that renewal of the wearing course, which is necessary periodically, is seldom accomplished without damaging the membrane, resulting in the need for replacement of the entire waterproofing system.

Overlays -- A second concrete course without a membrane can also be utilized to protect the reinforcing steel. This method, besides reducing the permeability, also stiffens the structure and lessens the probability of cracking due to flexing. The overlay can be conventional good quality concrete, or low-slump, dense, low water-cement ratio (0.32) concrete, which is preferable. When the latter type is used ("Iowa Method"), the two concrete courses are bonded together with a suitable mortar. After placing, the concrete has to be thoroughly consolidated because, despite the low water-cement ratio, low permeability will not otherwise be achieved, High range water-reducing admixture gives strong concrete by increasing the workability. Because overlays are thin (they can be as low as 32 mm and no more than 50 mm thick) special care has to be taken in curing in order to avoid cracking.

The overlays frequently contain large quantities of a special admixture, normally a polymer. The most usual admixture is latex, an aqueous emulsion of rubber, which can be of various types such as styrene-butadiene, vinyl chloride, acrylic or other. Although latex-modified concrete overlays are not impermeable they significantly reduce the chloride ion concentration at the reinforcing bars.

Overlays can also be polymeric materials (containing no cement), the most common being polyester or epoxy, to which fillers are added. These courses are no more than a few millimetres thick.

Sealers -- To reduce permeability, the application of a sealer has been recommended as a simple method to increase the durability of reinforced concrete. Modest success has been experienced with various types of sealers, of which the most common, and perhaps as effective as the more expensive materials, is linseed oil. The treatment consists of two applications of boiled linseed oil diluted with kerosene or mineral spirit in 1:1 ratio, to facilitate permeation into the pores of concrete. (Caution has to be exercised with this flammable and toxic solvent when applied in an enclosed space.) According to test results. linseed oil, as well as other sealers used in this application, does not prevent penetration in general but, under certain conditions, may retard chloride penetration.

Making the reinforcement the cathode

As explained earlier, in the galvanic cell the metallic ion at the anode goes into solution and the reaction products accumulate at the cathode. Reinforcing steel is protected from corrosion when acting as the cathode. At present, two methods are known which follow this approach.

Galvanized steel -- If coated with zinc, steel will in a corrosion process act as the cathode, and the zinc, as the anode. This protection is a temporary one as zinc corrodes in the alkaline environment of concrete. No unanimity of opinion exists concerning the benefits of this approach.

Cathodic protection -- In this electrochemical method zinc or cadmium, a less noble metal, is used not as a coating but as an independent electrode, which is replaced periodically when necessary (sacrificial anode). In a variation of this, the steel is coupled with a permanent electrode (e.g., carbon) and from an outside direct-current power source, potential is imposed in such a manner that the steel is made the negative cathode and the auxiliary anode is the positive pole in the cell.

Both variants of cathodic protection have been used successfully to prevent corrosion of pipelines, containers and ships, but only in the last decade have they been applied to protect bridge decks, and very recently, to parking decks. Undoubtedly, these methods could be successful for parking structures, but they involve the added weight of the coke breeze with an asphalt binder which is used as the anode. Of course, these add to construction and maintenance costs.

Corrosion inhibitors

Certain chemicals are known to minimize or completely stop the corrosion process. The mechanism through which these corrosion inhibitors function is not clear in all cases. One of these, calcium nitrite, is suitable for use as an admixture in concrete as it does not adversely affect the properties of concrete. It has been suggested that calcium nitrate reacts with ferrous ions to form a film of ferric oxide around the anode inhibiting further corrosion activity. The duration of the protection, however, is not known.

The use of corrosion inhibitors in concrete began only recently and experience gained to date is insufficient to reach conclusions on the merit of this method.

Conclusion

If costly repairs caused by the corrosion of the reinforcing steel are to be avoided, garage decks cannot be designed and built like ordinary office building floors. Corrosion can be prevented or at least minimized by using epoxy-coated steel, low water-cement ratio concrete, waterproofing, and good drainage. Whereas each of these measures is valuable in itself and will result in reduction of the rate of corrosion, several protective measures should be used simultaneously. To apply all available protective measures is unnecessary and prohibitively expensive. On the other hand, insufficient protection leads to unacceptable performance and high repair costs. The degree of protection required for a given garage depends on a number of technical and economic factors, such as type of design, type of construction, volume of traffic, type of occupancy, etc. Judicious selection of the measures has to be based on the experience of the designer and the owner, but the minimum requirement is that no garage should be built without a good drainage system, at least 5 cm concrete cover over the reinforcing steel, and a reliable waterproofing system.