The Parking garage problem

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THE PARKING GARAGE PROBLEM

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Although estimates are not accurate, it is clear that over $3 billion will have to be spent to restore deteriorated parking garages. By examining the mechanism of corrosion of the reinforcing steel - the chief cause of deterioration - practical means to avoid or at least retard the galvanic reaction can be identified. The use of salt as deicer has benefits but at a very considerable cost. A description of what has and is being done in an organizational way to aid users and the industry will be given. Beyond the technical aspects the question arises why the parking garage problem was not avoided and what built-in safeguards are in place which will identify the emergence of a potentially costly problem at an early stage.

LE PROBLÈME DES GARAGES DE STATIONNEMENT

Malgré l'absence d'estimations précises, il est clair que plus de 3 milliards de dollars devront être dépensés pour réparer les garages de stationnement. En étudiant le mécanisme de la corrosion de l'acier d'armature (cause principale de la détérioration des garages), des moyens pratiques pour éviter ou du moins pour retarder l'action galvanique peuvent être déterminés. L'utilisation des sels de dégivrage comporte certains avantages mais à un coût très élevé. Cette communication traitera des mesures prises par certains organismes pour venir en aide aux utilisateurs et à l'industrie. Au-delà des problèmes techniques, on tentera d'expliquer pourquoi la détérioration des garages de stationnement n'a pu être évitée, et on indiquera les moyens de protection qui existent à l'heure actuelle et qui permettent de déceler les premiers signes de désordres qui pourraient s'avérer coûteux.

THE PARKING GARAGE PROBLEM

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INTRODUCTION

The deterioration of parking garages, particularly those underground, became widespread in the mid-1970's. The incidences were not due to unique circumstances but rather were manifestations of a problem that would sooner or later affect almost every such garage in existence.

Considerable progress has been made in the past eight or ten years to formulate design and construction practices for newly built garages and to devise means to deal with those that have deteriorated. Although some important questions are still unresolved, a survey of the present situation and a review of the history of events is useful at this time.

It is well worth examining how the parking garage problem developed in searching for an answer to the important question: Why did the safeguards to prevent adoption of inadequate practices fail? The lesson learned from this exercise is of more than academic interest; if problems arose once, similar expensive or dangerous ones may develop again.

TECHNICAL BACKGROUND

Cracking, break-up and spalling of suspended concrete slabs leading to leaking ceilings in indoor garages are caused, with very few exceptions, by corrosion of the embedded steel.

Mature, fully cured portland cement concrete contains large quantities of lime that renders it strongly alkaline (pH between 12 and 13), an environment in which steel acquires passivity, i.e., it does not corrode. If the concrete is depleted of lime, the steel becomes depassivated and corrosion can take place. But even if high alkalinity is maintained, in the presence of chloride ions the protective passive layer on the surface of the steel does become destroyed, and should moisture and oxygen become available, corrosion will occur. The chemicals commonly used as deicing agents are chloride salts of sodium and calcium which, mixed with snow, are carried by vehicles into the garage. Thawing produces a brine that will penetrate unprotected concrete, raising the chloride concentration around the steel to high levels.

Once corrosion begins, the increased volume of the rust and other effects will cause the concrete envelope to crack and to spall and in the so-created pothole the steel is exposed to moisture and oxygen. As corrosion proceeds the bond between the steel and concrete fails progressively, leading potentially to structural impairment.

DEFENSIVE STRATEGIES

Although chloride ions are the prerequisite to corrosion of reinforcing steel, to ban chloride-based deicers is beyond the powers of building regulatory authorities. The chances of persuading provincial and municipal governments to prohibit the use of chloride deicers are slim, as no suitable alternate exists. They are likely here to stay, at least for the time being, and if damage is to be avoided the built environment has to be protected against their harmful effects.

CORROSION PROCESS

Corrosion is an electrochemical process that can best be described by considering a simple model of a galvanic cell as shown in Figure 1. In this example the cell consists of iron (Fe) and copper (Cu) electrodes partly immersed in an aqueous solution of some salt.

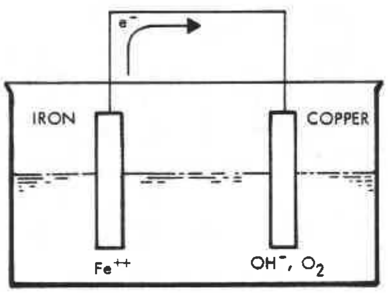

FIGURE 1

SCHEMATIC DIAGRAM OF GALVANIC CELL

Metallic iron in the presence of moisture and oxygen tends to revert to iron oxide, its stable state. In the first step of this process, the metallic iron goes into solution (anodic reaction) in the form of positively charged ferrous ion (Fe^{++}). The two electrons carrying the negative charges are separated and remain in the metal:

$$Fe \rightarrow Fe^{++} + 2e^-$$

Accumulation of the negative charges in the metal prevents further dissolution of the iron as ferrous ions. In the presence of a second electrode such as copper, a galvanic cell is formed in which electrons are consumed by the following reaction:

$$2e^- + \frac{1}{2} O_2 + H_2O \rightarrow 2OH^-$$

This reaction converts oxygen and water into hydroxyl ions, which in turn react with the ferrous ions and form a ferrous hydroxide precipitate; in the presence of oxygen this is converted to ferric hydroxide, the familiar reddish brown rust.

The presence of copper is not necessary for the corrosion process. In concrete decks galvanic cells form usually between two areas with different electrochemical properties of the reinforcing steel (Figure 2). These differences may be due to composition, physical (e.g., different levels of stress as a result of shaping) or environmental (e.g., different concentrations of chlorides, other salts or oxygen) factors.

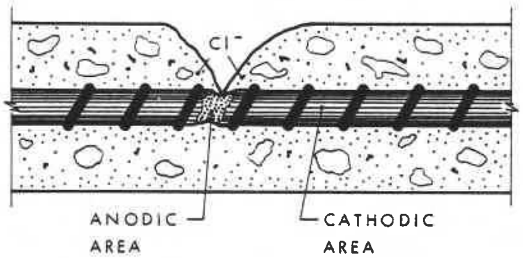

FIGURE 2

SCHEMATIC DIAGRAM OF GALVANIC CELL FORMATION IN A REINFORCED CONCRETE DECK

PREVENTIVE METHODS

To intercept the functioning of the galvanic cell, thus the corrosion process, at least one of the following essential elements has to be made unavailable in the concrete slab:

- the anode and cathode (or anodic and cathodic areas)
- electrical continuity between the anode and cathode
- electrical continuity in the medium surrounding the metals
- moisture
- oxygen
- chloride ions.

Because complete control of the electrochemical properties of all embedded metals is not possible, the viable options for protection are electrically isolating the steel (usually with epoxy) or preventing chloride ions from reaching the steel. This means making the concrete as impervious as possible by:

- using a low water/cement ratio
- curing well
- increasing the thickness of cover and
- applying a surface sealer, or
- installing a waterproofing membrane, or
- installing an impervious latex cement topping.

Two other special measures are cathodic protection and corrosion-inhibiting admixtures. The latter method consists of adding an admixture to the plastic concrete mix. Inhibitors, such as calcium nitrate, in sufficient concentration have been found to prevent or greatly minimize corrosion of steel. The main drawback of this method is that because the admixture is consumed by the protective action, in time its inhibitive action is decreased if the intensity of the corrosive action is underestimated at the time of construction.

Cathodic protection arrests corrosion by providing highly negative potential to the steel, rendering it the cathode with respect to an inert electrode. This method has been used with great success for the protection of pipelines and ships. For parking garages its effectiveness depends on the solution of the practical problems of the given installation.

Rehabilitation of deteriorated garages and the designing of new ones are covered in other papers in this session and therefore are not discussed here in further detail.

REVIEW OF THE ORGANIZATIONAL MEASURES

Since the recognition of the parking garage problem in the 1970's, the first task was to establish the magnitude of the cost of repair. Because of lack of data on the number of parking garages in Canada, their total floor area and the degree of deterioration, it was not possible to estimate reliably the dollar value of the damage. It is clear, however, that the cost of repair is of the magnitude of several billion dollars and thus a major effort towards finding a solution to the problem is well justified. Answers to two questions were required urgently:

- How does one repair deteriorated garages?
- How does one design and build new garages that will last as long as the building they serve?

The formulation of repair strategies and the establishment of new design guidelines are made difficult by the dearth of examples of garages that are performing well. Most durability problems, such as damage due to freezing and thawing, are the result of deviation from the standard practice or outright disregard of proven principles. The parking garage problem was somewhat different, in that the standard practice for design and construction was inadequate. The situation was that before the question as to how to build a durable garage could be answered, it had to be established whether it was indeed possible to build a garage that would perform well for decades.

The contribution of the Ontario Chapter of the American Concrete Institute has to be recognized. It formed an ad hoc committee (under the chairmanship of J. Bickley) that prepared an interim guideline for the investigation, repair, design and construction of parking structures (Ontario Chapter Committee on Parking Structures, 1981). In the same year the Division of Building Research (DBR) of NRC commissioned a report "Parking Structure Deterioration: Information and Analysis" (Trow Ltd., 1981) and Canada Mortgage and Housing Corporation (CMHC) financed a study the next year on "Nature, Extent and Impact of Residential Parking Structure Deterioration" (Trow Ltd., 1982). A review of information available at the time was published by DBR in its Canadian Building Digest Series in 1982 — No. 224, "Deterioration of Indoor Parking Garages" (Litvan, 1982a) and No. 225, "Evaluation and Repair of Deteriorated Garage Floors" (Litvan, 1982b). A demonstration project to evaluate the feasibility of cathodic protection in parking garages was jointly sponsored by DBR and Public Works Canada (PWC) in 1984. A major investigation involving the survey of 300 garages was also jointly financed by CMHC, NRC, PWC and Supply and Services Canada, and was completed recently (Trow Ltd., 1985).

Based on these studies and experience gained, it is generally recognized that durable parking garages can be built and only the level of protection required to achieve this objective need be better defined, resulting, it is hoped, in a simplified construction method and a saving in overall cost. At present, according to the consensus, multilevel protection is thought to be necessary; no single protection measure such as the installation of a waterproofing membrane or utilization of epoxy-coated reinforcing bars is, in itself, deemed to be sufficient. This approach is outlined in Technical Builder's Bulletin No. 7 of CMHC (revised edition to appear shortly) and in the Standard on Durable Parking Garages being prepared by the Canadian Standards Association.

Significant progress has thus been made regarding the proper design and construction of durable parking garages; helpful guidelines are already available or will be very soon. Guidance for selecting a waterproofing membrane or a surface sealant is still not available. A committee of the Canadian General Standards Board has been formed to prepare a standard for waterproofing membranes but its publication may take some time. In the meantime, selection must be based on field performance.

A single repair technique for existing deteriorated garages cannot, of course, achieve lasting durability. If concrete is largely contaminated with deicing salt it cannot be restored fully to give trouble-free service over several decades. The objective of the repair is to restore structural integrity so that the service life of the garage can be extended as much as possible. It is almost certain that further repairs during the lifetime of the structure will be required but it is hoped that the useful life of deteriorated garages can be extended to equal that of the buildings they serve.

SOME REFLECTIONS ON THE DEVELOPMENT OF THE PARKING GARAGE PROBLEM

The analysis of the circumstances that led to the billion-dollar problem of parking garages is of more than historic interest. Another similarly costly problem may develop unless safeguards are put in place.

The National Building Code concerns itself mainly with safety and health-related aspects of design. It has not prevented, and is not expected to prevent, the emergence of problems such as the deterioration of garages. Market forces are thus the sole defence against making costly mistakes. Obviously owners and developers will not patronize those who do not design durable buildings. But this force protects only against obvious substandard design and workmanship. Once a faulty approach becomes the norm, almost insurmountable difficulties face those who would advocate a better quality and more expensive design. The owner and the designer want clear evidence that the more economical design will fail. A more expensive option will be selected only when it is proven beyond doubt that the more economical design will fail. In addition, the fact that subsequent repair costs will be offset by savings in interest charges due to the reduced capital expenditure, by tax advantages and, in case of rental property, by maintenance costs chargeable to the tenants, can be an important consideration.

It takes several years to prove the inadequacy of a particular design. In the case of the rather rapid parking garage deterioration, the first symptoms may not be observable in the first three to five years of service. Processes of deterioration can be much slower, extending to 20 or 30 years, yet the life span of most buildings is much longer than that. Obviously, performance in such cases is difficult to predict. A current concern illustrates this point. It is not known whether concrete containing secondary cementing materials such as fly ash, slag or silica fume will, after 20, 30 or 40 years of exposure to carbon dioxide, have enough lime to protect the embedded reinforcement from corrosion. We know that concrete made from blended cement contains less lime than that made from ordinary portland cement and that it is less permeable (at least at early ages) than conventional concrete. As discussed earlier, high lime content is essential for the development of passivity of steel and for protection against corrosion of the metal. We hope that lower permeability will compensate for the reduced lime content but this is not yet proven.

There are, of course, no easy solutions to the general problem. Regulatory action cannot be taken for each of the perceived problems, and advocating a more expensive solution to potential problems without evidence would be irresponsible.

One important document that is at present unknown in the building industry is the owner's manual. It is a curious fact that while no industrial product of any complexity is sold without a manual and operating instructions, multimillion-dollar buildings are handed over to the owners without a word of instruction, caution or advice. More often than not, even the drawings are of limited use because they describe what was designed at some stage of the development and not what was built. The purchaser of a toaster receives a trouble-shooting manual but the owner of an eighty-storey building receives no such assistance to solve problems.

An owner's manual would be helpful by drawing attention to potential problems, and giving a timetable for preventive maintenance and a replacement schedule for certain components. Perhaps just as important would be the benefit derived from forcing the designer to think in terms of durability and performance.

Uncertainties or doubts about problems, such as carbonation of concrete, could be recorded in the documents with details on frequency and nature of testing. Perhaps the parking garage problem would have been less serious if such a monitoring system had been adopted.

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REFERENCES

Ontario Chapter Committee on Parking Structures, 1981. American Concrete Institute, Interim Guidelines, Investigation, Repair, Design and Construction of Parking Structures, Toronto.

Litvan, G.G., 1982a. Deterioration of Indoor Parking Garages, Division of Building Research, National Research Council Canada, Canadian Building Digest No. 224, Ottawa.

Litvan, G.G., 1982b. Evaluation and Repair of Deteriorated Garage Floors, Division of Building Research, National Research Council Canada, Canadian Building Digest No. 225, Ottawa.

Trow Ltd., 1981. Parking Structure Deterioration: Information and Analysis, T-2298-C, prepared for National Research Council Canada, Ottawa.

Trow Ltd., 1982. Nature, Extent, and Impact of Residential Parking Structure Deterioration, T-2173-C, prepared for Canada Mortgage and Housing Corporation, Ottawa.

Trow Ltd., 1985. Parking Structure Deterioration: a Survey and Analysis of its Extent and Influencing Factors, T-4010-C, prepared for Canada Mortgage and Housing Corporation, National Research Council Canada, Public Works Canada and Supply and Services Canada, Ottawa.