RESEARCH HIGHLIGHT

Technical Series 00-128

Parking Structure Deterioration: A Survey and Analysis of its Extent and Influencing Factors

INTRODUCTION

In 1981, CMHC commissioned a visual survey of 84 parking structures attached to apartment buildings in the Ottawa area.The results were subsequently published in a report entitled,"The Nature, Extent and Impact of Residential Parking Structure Deterioration." That report was the first survey of its kind in Canada. As a result of that survey, CMHC, in cooperation with the National Research Council, Public Works Canada and Supply and Services Canada, decided to proceed with a subsequent study.

The objective of this study was to:

- Identify those factors that favourably affect the serviceability of parking structures;
- Identify cost-effective repair strategies;
- Identify suitable operation and maintenance procedures to be used after repairs are made;
- Provide relevant information to codes and standards writing committees.

RESEARCH PROGRAM

The study consisted of a survey and analysis of the extent of deterioration in over 300 parking structures (Table 1) and the factors influencing that deterioration.Where visual surveys were conducted, they consisted of completing a simple field survey form.While a more detailed form was originally proposed, field trials proved it to be too cumbersome.

Where detailed surveys were undertaken, they were conducted on interior suspended slabs over approximately 10 per cent of the area, in a location chosen to be representative of the condition of the total area. Fieldwork consisted of the following steps:

1 **Grid layout:**The test area was divided into a 2 m x 2 m grid system using the columns and perimeter walls as reference points.

2 **Delamination Survey:**The test area was examined for possible delaminations using the chain-drag method, a simple sonic test in which a heavy steel chain is dragged across the surface and areas of delamination are characterized by a dull sound.

3 **Visual Survey:**This phase of the detailed survey consisted of mapping cracks, spalls, impending spalls, exposed reinforcing bars, leaching and honeycombing on the complete soffit of the suspended levels and on the top surface of the test areas.

4 **Half-cell Survey:** A survey of the test areas for corrosion activity was carried out using a copper-copper/sulphate half-cell based on the ASTM Standard C876,"Half-Cell Potentials of Reinforcing Steel in Concrete." The method consists of connecting a wire to the cleaned exposed top reinforcing bar and connecting from this point, via a voltmeter, to the copper-copper/sulphate half-cell, which is placed at each grid point.The measured voltage potential can be related to the corrosion activity of the reinforcing steel.

5. **Cover meter Survey:** This test uses an electro-magnetic detecting instrument which responds to ferrous metals, to approximate the concrete cover to the top reinforcing steel in the test areas.

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Table 1

Project Series	No. of Structures	No. Surveyed in this Project	Remarks
A	16	16	Part of the original CMHC survey of 84 garages, representing 16 of 20 garages with repair estimates of less than $100 per parking space. Visual surveys were conducted on these garages.
B	4	4	Detailed surveys of underground and above-ground structures, including office/shopping complexes in Ottawa and Montréal and a post-tensioned structure in Toronto.
C	11	11	Parking structures nominated by CMHC and Public Works for monitoring the effectiveness of repairs, including underground and outside parking structures for residential, hospital and retail buildings, in Toronto, Ottawa, Hull, Kitchener, Hamilton, London and Montréal. The repair products used for each garage are identified generically in the report.
D	11	11	When it became difficult to find multi-storey underground garages without some degree of deterioration, visual surveys of these above-grade garages considered to be in good condition were added.
E	22	22	In 1982, the Ontario Housing Corporation surveyed its 159 parking structures and rated them on a scale from 1 (no significant deterioration) to 10 (extremely advanced deterioration). Twenty-two of these structures, representing those rated at 1 or 2 in the 1982 survey, were visually reviewed.
F	3	3	These three garages represent the only garages of approximately 100 found to be in good condition in the summer of 1983 when the Building Commissioner of North York had a survey of its parking garages conducted.
Trow Database	175		These garages represent surveys Trow has carried out for private clients, ranging from brief superficial visual surveys to detailed surveys and are used to provide background norms for various aspects of this investigation.
Balance of CMHC survey	68		The balance of the 84 structures in the CMHC survey not included as one of the sixteen structures in Series "A".
Totals	**310**	**67**	

6. **Component Survey:** A visual survey was made of those components, other than the parking levels slabs that form the parking structure.
7. **Coring:** A diamond drill was used to obtain 100 mm diameter cores, including those removed for the half-cell test.The cores were used to: determine the chloride ion content in the concrete; determine the compressive strength of the concrete; verify delaminations within the concrete slabs, to obtain electrical contact with the reinforcement for the corrosion survey, to verify the condition of the reinforcing steel and to determine the air void system of the concrete.

RESULTS

Factors Affecting Serviceability

The "A" series garages that were included in the study because they exhibited little or no damage all had similar characteristics.These garages were generally found to be small, slab-on-grade structures, none with a suspended slab. All garages were small, roof-parking structures; varying between 1 and 150 spaces. Eleven of the structures were waterproofed and on three, the roofs were partially or wholly landscaped.The roofs gave evidence of good waterproofing practices, including appropriate flashings and drainage.

The "E" series structures suggest that the main source of problems in underground garages is suspended slabs and, where these are eliminated, a significant portion of the problem disappears. In addition, although roofs are often a source of major problems, where no parking is allowed on roofs the problem becomes much smaller. Finally, this sample provides reasonable evidence that there is a relationship, although not quantifiable, between the amount of usage and the amount and rate of deterioration.

Three "F" series garages reported to be in good condition were found to be in poor to fair condition. Of significance though, was the fact that these garages were not waterproofed, yet had provided 19 to 22 years of service prior to needing extensive rehabilitation.These garages pre-date the use of ultimate strength design criteria, or limit-states design.The change from working stress design to ultimate strength design, which occurred in about 1970, led to the use of less reinforcement in slabs and the occurrence of wider cracks. It was found that garages built prior to ultimate strength design proved to be more durable than those built subsequently.

A cast-in-place, post-tensioned structure was found to be in excellent condition 11 years after construction. The conclusion drawn was that with good maintenance, including periodic resealing, a post-tensioned structure built to high construction standards could provide a good service life with minimal maintenance. (However, it has since been found that these structures, too, can experience significant deterioration and research continues into evaluation techniques for post-tensioned structures.)

The results of Series “B” and “C” were compared to the norms derived from the overall Trow database and some general conclusions were drawn.

Cracking: Subjectively, most parking structures appeared to be extensively cracked. However, when the extent of cracking was evaluated by objective criteria, the incidence of cracking was found to be not as great as believed.The conclusion drawn was that parking decks are not as badly cracked as had commonly been supposed. At the time of this study, the influence of cracking on corrosion was not fully understood, with one theory being that cracking had little effect. (It has since been found that while cracking has little impact on the total area of top steel corrosion, it is significant in bottom steel corrosion. Most major cracks occur mid-span between columns, which also happens to be the location of the bottom steel. Chloride-laden water passing through cracks causes bottom steel to corrode.)

Scaling: Scaling was not found to be severe, nor was it a significant factor in the overall condition of any of the structures surveyed in this study. (Since this study, slab concrete has generally been air-entrained when placed, further reducing the likelihood of scaling.)

Delamination: In most slabs, delamination of the top surface only occurs where there is top steel, so only a proportion of the total area can delaminate. Delaminations increase with time and the rate of increase is highly variable. Factors affecting the rate of increase were not quantitatively determined, but it was generally believed that usage, cover thickness, humidity, temperature and concrete quality are factors. (Delamination continues to be the most significant problem facing owners of garages. Many owners are now on their second or third series of repairs.)

Concrete cover: Adequate and/or uniform cover was found in the structures seen to be in good condition. The concrete cover specified for the garages in the survey was normally 19 mm, as at the time of their design, garages had not been considered corrosive environments.While the average cover was generally in excess of that specified, it was noted that not only was the cover frequently inadequate, but there was a very wide variation in the amount of cover—up to 100 mm or more.The standard deviation in cover depth based on the covermeter testing was found to be greater than 10 mm.The study suggests that to achieve 95 per cent compliance with minimum cover requirements, and considering actual construction tolerances, a significant increase in the thickness of the slabs is required. Further, standards of placement need to be improved. (Increased cover to reinforcing steel requires changes in structural design. Generally, however, slabs have been provided with waterproofing, allowing specified concrete cover to reduce from 50 mm to 40 mm. Reference CSA S413-94, "Parking Structures".)

Movement joints: In most of the structures surveyed, there appeared to be an appropriate number and location of movement joints. In general, however, the method of forming such joints, and the joint system itself, were susceptible to distress. Such distress could have serious structural significance due to loss of bearing from spalling. Sealing of these movement joints to prevent the ingress of water, oxygen and chlorides was also found to be extremely important.The use of unsuitable joint sealing systems, and deficient installation workmanship were seen to be two main problems. (Expansion joints, even in new waterproofed garages, still tend to be problematic, having a seal lifespan of roughly 10 to 15 years.)

Quality of concrete: Strength of concrete is not itself a measure of durability.Typically, none of the projects specified a very high quality concrete. However, even though concrete with a maximum water-cement ratio of 0.45 and a minimum cover of 50 mm might extend the life of the slab, it alone would not be sufficient to guarantee a long life slab. (Current standards require Class C-1 0.40 water-cement ratio concrete with a minimum 28-day strength of 35 MPa. Reference CSA A23.1-94.)

Chloride content: An analysis of the chloride levels found that the mean was twice that found in bridge decks in North America.The codes at the time of this study allowed the addition of commercial calcium chloride to concrete to as much as two per cent by weight of the cement. (CSA Standard S413-94, Parking Structures, now allows a maximum of only 0.06 per cent calcium chloride by mass of the cementing material.)

Other factors: Nothing noted in the surveys showed any significant deviation from codes of construction in place at the time, except that the design and construction of expansion joints often failed to follow the best practice or even good practice.There was no evidence that the framing, floor system or the sizing of any elements was, of itself, a factor in deterioration.The only area where, subject to other factors, sizing could be a factor in deterioration would be in floor slab thickness. It should also be noted that the use of corrosion resistant reinforcement post dates the study sample.

Repairs

The effectiveness of repairs and protective systems is best judged by the rate of further deterioration since repairs.While it had been suggested that between 0.25 per cent and one per cent of the value of a structure should be budgeted annually for maintenance of the structure and protective systems after it has been repaired, the report suggests that this figure may need to be as high as two per cent. (Current thinking is that, for garages originally constructed without waterproofing, the figure could be much higher, but based on actual quality of concrete use and maintenance.)

The data from “D” series shows that sealers can provide good protection, but that sealers do have to be renewed to provide protection. Although asphaltic overlays were found to offer some protection in some structures, their permeability can vary from none to very high and therefore cannot be relied upon to act as waterproofing. Similar variability was found with concrete overlays.

No definitive information is provided in the report with respect to cost-effective repairs as it was felt that there is not yet adequate information available to enable a cost-effective choice to be made based on life-cycle costs and performance. It was recommended that the most suitable and compatible materials should be chosen based on the repair team’s experience. (In the period 1995 to 2000, while conventional delamination repair was still common, the replacement of slabs, or at least the complete upper 75 mm to 100 mm, has become more and more frequent. This is in response to high costs for repeated conventional repairs.)

Maintenance

The National Parking Association of the United States, through a committee of engineers and others with extensive experience in this area, produced a parking garage maintenance manual in 1982. It was found to be a very well produced, comprehensive and relevant document for parking garages in Canada. Rather than commit further project resources to this aspect of the project objectives, the report includes the *NPA Parking Garage Maintenance Manual* in an appendix. (That maintenance manual is still referenced in 1999-2000.)

The following factors have been shown by the data in this study to contribute to durability:

Design:	Crack-free design Good quality expansion joints Adequate provision for movement Good cover (about 40 mm in exposed structures) Good drainage Air entrainment (in exposed structures) High quality waterproofing system protected from wear Sealers replenished periodically.
Construction:	Uniform cover Good quality concrete, including adequate air-void system, adequate chloride impermeability, adequate strength and well finished. Good slope for drainage No construction induced deflection or cracking
Usage:	Low usage rate Maintenance Re-sealing of exposed decks.

Paying attention to these factors in the design, construction and usage of a parking garage should reduce deterioration and prolong the life of the structure. CSA S413-94 now specifies requirements for design of parking garages and CAN/CSA A23.1 has material and construction requirements suited to the exposure conditions of garages.

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Research Report: *Parking Structure Deterioration: A Survey and Analysis of its Extent and Influencing Factors.*

Housing Research at CMHC

Under Part IX of the ***National Housing Act***, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research.

This fact sheet is one of a series intended to inform you of the nature and scope of CMHC's research.

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