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**INVESTIGATION INTO DEVELOPMENT
OF DETERIORATION CURVES AND
PREDICTION MODELS FOR CONCRETE
BRIDGE DECKS IN ONTARIO**

by

ANNETTE EBBINGHAUS

A thesis
presented to the University of Ottawa
in fulfilment of the
thesis requirement for the degree of
M.A.Sc.
in
CIVIL ENGINEERING



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ABSTRACT

The deterioration of highway structures in Ontario due to the use of de-icing salts during winter maintenance operations has resulted in costly rehabilitations or replacements of structures in as little as 15 years after the time of construction. This has prompted several organizations to search for new materials and methods of design and construction to increase durability. The need to maintain existing structures, and lengthen the long-term service of new structures, has become increasingly important. The inventory of bridges continues to grow, but at an ever-slowing pace as the highway infrastructure nears completion. Yet, as the population becomes more mobile and the dependence on rail transportation diminishes, the burden on the highway system will only increase. Therefore maintenance of the existing highway structures is of great importance. This thesis is written with the intent to aid the Ontario Ministry of Transportation in their quest to manage and maintain the provincial highway system through utilizing the data collected during the detailed bridge deck condition surveys to determine the most economical time to rehabilitate or replace a structure. The Ministry of Transportation of Ontario presently has jurisdiction over approximately 3,200 of the bridges in Ontario. Approximately one third have been rehabilitated in the last decade. The approximate cost, of these rehabilitation projects varied from a high of \$68 million in 1982 to a low of \$36 million in 1983 and \$550 million in the last decade (amounts in 1990 dollars). Appropriate assessment of deterioration conditions and the ability to predict the proper timing for

rehabilitative intervention to most effectively preserve and maintain Ontario's highway infrastructure is of great concern to the Ontario Ministry of Transportation.

Bridge decks are subject to severe environmental influences such as cycles of freeze-thaw, de-icing salts and wear and tear from traffic use, and it is a horizontal surface where moisture can readily pond. The heavy use of de-icing salts during winter snow and ice storms increases the probability of deterioration of concrete bridge decks because it introduces an aggressive ion to the surface of the concrete deck. When the salt solution penetrates the concrete surface and initiates corrosion of the reinforcing steel, cracking, followed by rupture of the concrete and eventual spalling of the concrete surface occurs. Once this process has started it is irreversible and if left unattended, may cause structural failure.

It is accepted that the economic life of a structure can be extended through timely maintenance intervention based on expected deterioration levels extrapolated from the quantity of deterioration measured in the detailed condition surveys. The detailed condition surveys conducted by the Ministry from 1978 through 1990 were used as the data source. The data was input into a database and analyzed to develop deterioration curves to estimate future deterioration levels for three types of bridge deck protection, namely: exposed concrete, asphalt covered, and asphalt with waterproofing. The database presently contains 640 structures with 175 of these containing the data collected from two consecutive detailed condition surveys. Of these 175 structures, 131 contained information that was useful for this thesis.

Three sets of curves were developed; Deterioration versus Age, Deterioration and Concrete Cover Contours, and Rate of Deterioration versus Age. For the development of these curves deterioration was defined as the percentage of the deck area with embedded reinforcing steel undergoing active corrosion (half-cell potential measurements more negative than -0.35 volts indicates a 90% probability that corrosion of the reinforcing steel is occurring at the time of testing). The Deterioration and Concrete Cover Contours and the Rate of Deterioration versus Age curve considers the effects of age, concrete cover, and the type of deck surface protection on the corrosion of the deck reinforcement.

The shapes of these curves indicates that corrosion of the concrete deck reinforcement occurs more rapidly if the deck surface is left unprotected. The results from the various regression analyses conducted for all of the curves developed emphasized the strong influence of "age" on the progression of deterioration and that the relationship is not linear.

Several recommendations can be made consequent to from the process of gathering data for the development of the deterioration curves in this study:

- use the deterioration curves developed as an aid in selecting the appropriate time and method to rehabilitate a bridge deck
- use the deterioration curves for estimating the quantity of concrete removals and areas of repair for future rehabilitation projects.
- better storage of structural condition records
- revise OSIS (Ontario Structure Inventory System) to include specific results of condition surveys or implement use of the database file presented in this thesis at Regional and District levels

It should be note that engineering judgement is, and will always be, an integral part of

these decisions. These curves should be used by engineers as a tool to confirm decisions to commit structures to the rehabilitation program.

It is also recommended that another study be conducted utilizing the data presently collected which would involve analyzing the growth of the probable corrosion potential range. This range of corrosion potentials is the percentage of the deck area with half-cell measurements between -0.20 V and -0.35 V. It appears that the decks which recorded an apparent drop in the active corrosion potential range had a large increase in the uncertain corrosion potential range. If "Total Corrosion Rate of Deterioration" curves are developed for the combinations of the percentage of the deck area in the uncertain range and in the active range of corrosion, subtracting the "total corrosion" rate curve from the active corrosion rate curve, the growth of the uncertain corrosion active range could be estimated. The growth of this range could then be related to the future rehabilitation needs of Ontario bridge decks.

In summary, this study can help the Ontario Ministry of Transportation make better decisions on the prioritization of bridge deck rehabilitations. The programs presently in place at the Ministry are effective in attempting to address the ever growing problem of deterioration of Ontario bridge decks. The Bridge Management Section has adopted a benefit/cost analysis to ensure that budgets for rehabilitating structures are effectively spent, as provincial funding for rehabilitations is not adequate to repair all deteriorated structures. Nevertheless, some method of prioritization must be utilized which considers both the level of deterioration of the bridge deck and the money available for rehabilitations.

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CHAPTER 1

INTRODUCTION

The deterioration of highway structures in Canada is a fact of life particularly in areas where de-icing salts are used. The resulting cost to rehabilitate or replace these structures has prompted several organizations to search for new materials and methods of design and construction to increase durability. These organizations have also been involved in developing bridge management systems to monitor the condition of existing structures. The need to maintain these structures, and lengthen the long-term service of new structures, has become increasingly important. The inventory of bridges continues to grow, but at an ever-slowing pace as the highway infrastructure nears completion. Yet, as the population becomes more mobile and the dependence on rail transportation diminishes, the burden on the highway system will only increase. Therefore maintenance of the existing highway structures is of great importance. Since fewer new structures are being built and fewer new routes and alignment changes on existing highways are planned, there is a tremendous need to rehabilitate existing structures.

The Ontario Ministry of Transportation presently has jurisdiction over approximately 3,200 of the bridges (span over 6 metres) in Ontario. Approximately one third have been rehabilitated in the last decade. Figure 1.1 shows that the fewest number

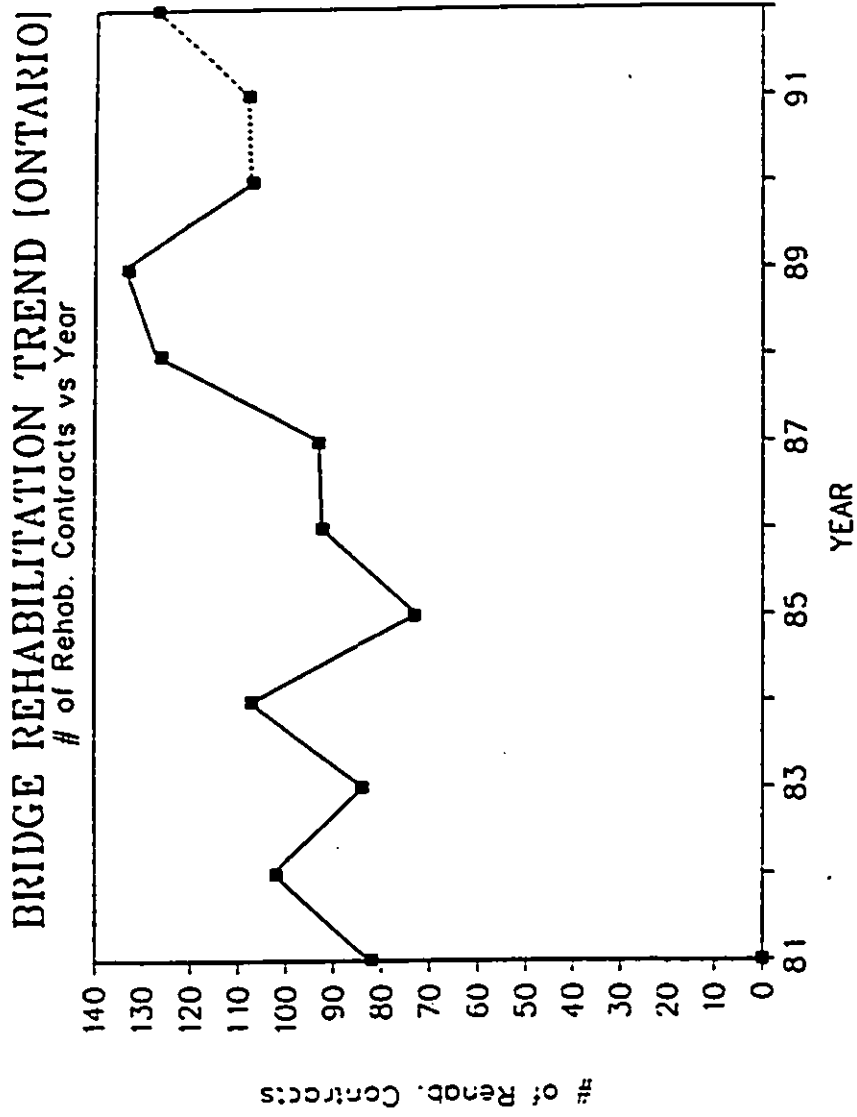


Figure 1.1 Number of Rehabilitations Performed Between 1981 and 1990

of bridges rehabilitated in any one year was 73 in 1985. The most rehabilitated in one year was 133 in 1989. The approximate cost, (shown in Figure 1.2 in 1990 dollars) of these rehabilitation projects varied from a high of \$68 million in 1982 (102 rehabilitation contracts) to a low of \$36 million in 1983 (84 rehabilitation contracts). The approximate cost (1990 dollars) of all the rehabilitations conducted in the last decade is \$550 million (see Figure 1.2). This figure illustrates the magnitude of the deterioration problem in Ontario. Appropriate assessment of deterioration conditions and the ability to predict the appropriate timing for rehabilitative intervention to most effectively preserve and maintain Ontario's highway infrastructure is of great concern to the Ministry.

The bridge deck component experiences the most severe environment of all components of the bridge. A bridge deck is subject to freeze-thaw cycles, de-icing salts, wear and tear from traffic use, and it is a horizontal surface where moisture can readily pond. Deterioration of bridge deck systems may be caused, singly or in combination, by the following: galvanic corrosion of the embedded reinforcing steel, alkali-aggregate reactions, cycles of freeze-thaw, fatigue, and excessive stresses due to the overloading of the structure.

Galvanic corrosion of the embedded reinforcing steel is discussed in detail in Chapter 4 as it is the most prevalent damaging type of deterioration in Ontario. The heavy use of de-icing salts during winter snow and ice storms increases the deterioration of concrete bridge decks, no matter what type, because it introduces an aggressive ion to the surface of the concrete deck. When the salt solution penetrates the concrete surface and initiates corrosion of the reinforcing steel, cracking, followed by rupture of the

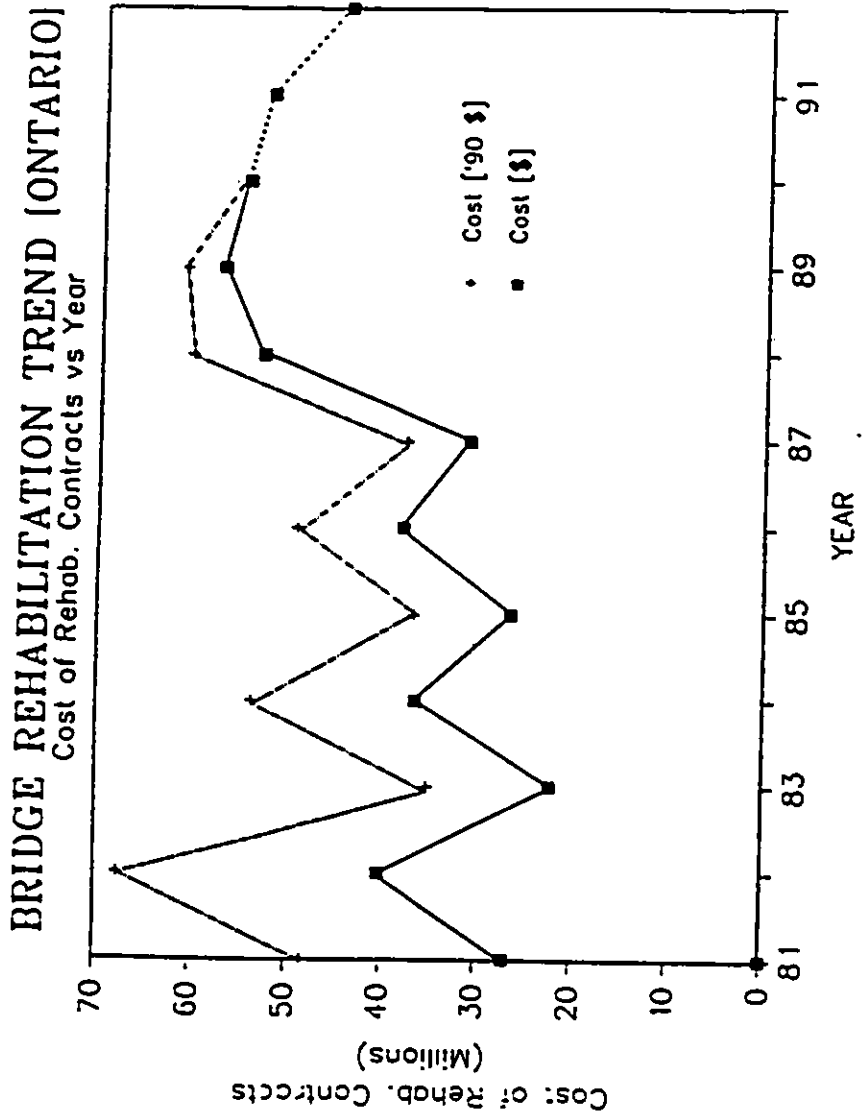


Figure 1.2 Cost of Rehabilitations Performed Between 1981 and 1990

concrete and eventual spalling of the concrete surface occurs. This type of corrosion is dependent on the presence of moisture, oxygen, and an aggressive chloride ion, such as that found in de-icing salts, at the level of a depassivated layer of reinforcement. Once this process has started it is irreversible and, if left unattended, may cause structural failure.

Alkali aggregate reactions can lead to expansion of concrete and the subsequent cracking of concrete. There are two types of alkali-aggregate reactions: alkali-silica/silicate and alkali-carbonate. The more common of the two is the alkali-silica reaction which is caused by the reaction of reactive silica, which is present in the aggregate used in the concrete mix, and sodium and potassium alkalis which are present in portland cement and water. The reaction produces an alkali-silica gel which has unlimited swelling capabilities. The increased volume of the gel in the concrete voids creates an internal pressure and causes a series of cracks to form in the unrestrained surface concrete. The alkali-carbonate reaction is the reaction which occurs when some types of dolomitic limestone aggregates come in contact with the alkalis in portland cement. The expansion of the concrete is similar to that of the alkali-silica reaction as the dolomite and calcium silicate hydrate produce magnesium hydroxide silica gel and calcium carbonate which yields a volume increase of approximately 4% (Reference 28). Cracks form around the reactive aggregates. This eventually leads to a loss of bond between the aggregate and the cement paste. This reaction is thought to be linked to the presence of clay in the aggregate. The Ontario Ministry of Transportation has strict specifications concerning aggregate types and sources. However, in some areas of the

province reactive aggregate sources have been used and severe cracking, and in some cases loss of strength, has resulted. This type of deterioration is not considered to be the major source of bridge deck deterioration for any of the structures included in this thesis.

Concrete's ability to resist freeze-thaw deterioration depends on the concrete's capacity for and probability of containing freezable water. In order for a concrete deck to be damaged from freeze-thaw cycles, voids within the concrete must be saturated at the time of freezing. As the water freezes in the voids and expands, pressure develops within the concrete matrix and damage results. The absorption of de-icers may also cause deterioration due to freeze-thaw as they melt snow and ice at the deck surface which keeps the concrete in a saturated state. In addition, de-icers cause a concentration of chlorides to develop in the capillary cavities creating osmotic flows within the concrete which also induces pressure within the concrete. Air-entrainment of concrete produces an excellent pore distribution network so that water expelled from the freezing sites will be taken up in these larger voids. Although air-entrainment of concrete was first introduced into the Ontario highway system in 1958, analysis of the structure data indicates that an effective method was not developed until about 1964 (see Chapter 6).

Scaling of the concrete surface is the most common type of freeze-thaw deterioration. In the early 1960s the major source of deterioration of bridge decks was severe scaling due to the effects of freeze-thaw. Scaling is thought to be caused by any of the following: (Reference 11)

- pressure from water flowing from porous aggregates
- hydraulic pressure which develops in the capillary voids just below the surface of the concrete

- accumulation of moisture in capillary voids below the surface freezes to form ice crystals
- osmotic pressure due to the presence of salts in the capillary voids immediately below the surface
- improper surface finishing causing surface concrete to differ in nature from underlying concrete
- use of de-icing salts which causes surface snow and ice to melt on the surface renewing moisture for additional freezing of surface and subsurface ice crystals
- artificial surface compaction which occurs during finishing.

This thesis is written with the intent to aid the Ontario Ministry of Transportation to manage and maintain the provincial highway system. The development of three sets of deterioration curves, namely; deterioration versus age, deterioration and concrete cover contour lines, and rate of deterioration versus age, using actual structure condition survey data will help determine the most economical time to rehabilitate or replace a structure.

The author organized a four month contract in fall 1990 with the Ministry to develop and update a database which stores structure deterioration condition information. This thesis concentrates on the measurements made during the detailed bridge deck condition surveys. The deterioration data was stored and analyzed to develop deterioration curves to estimate the future deterioration levels for three types of bridge deck protection, namely: exposed concrete, asphalt covered, and asphalt with waterproofing. The detailed condition surveys conducted by the Ministry from 1978 through 1990 were used as the data source. The Ministry's database presently contains 640 structures with 175 of these containing the data collected from two consecutive

detailed condition surveys. Structures with more than one set of detailed condition survey data were selected so that rates of deterioration could be assessed. Of these 175 structures, 131 contained information that was useful for this thesis.

The Ministry is divided into five Regions: Southwestern, Central, Eastern, Northern, and Northwestern. Each Region is subsequently split into Districts which number 18 in total. Figures 1.3 and 1.4 show the percentage of structures included in this thesis in the respective Regions and Districts and the boundaries of the Regions and Districts in Ontario are listed in Table 1.1. Eastern and Central Regions combined represent 64.1% of the structures used.

The remaining chapters of this thesis outline the processes undertaken to develop the various sets of deterioration curves based on actual deterioration data collected from the Ontario bridge population.

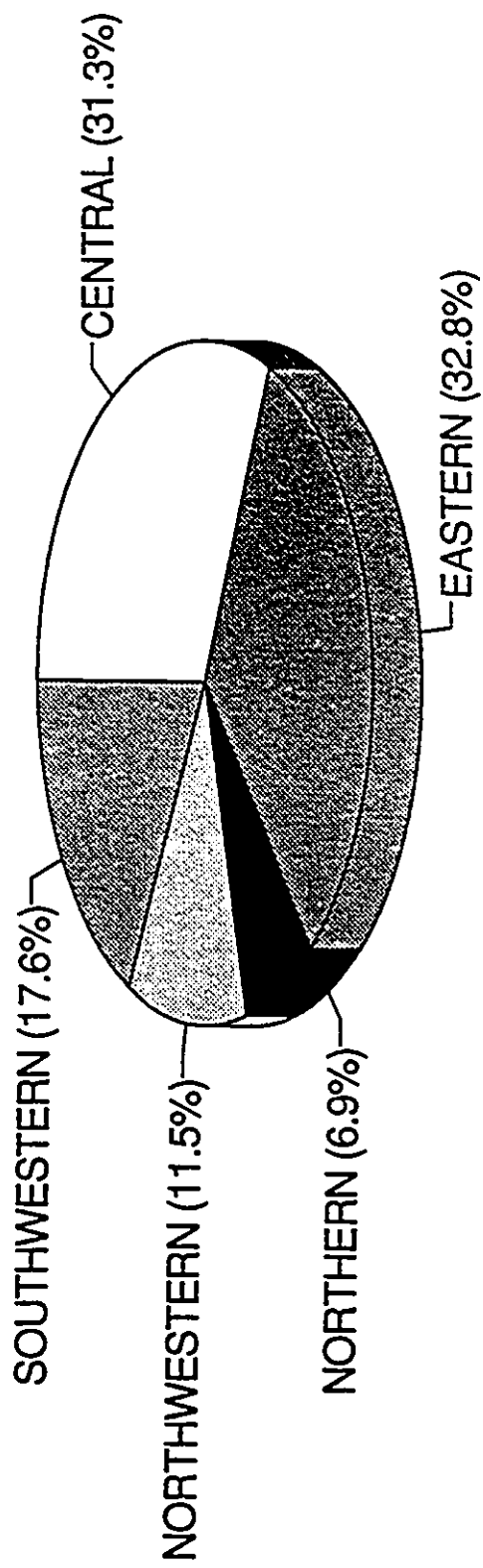


Figure 1.3
Regional Distribution
of Bridges Investigated

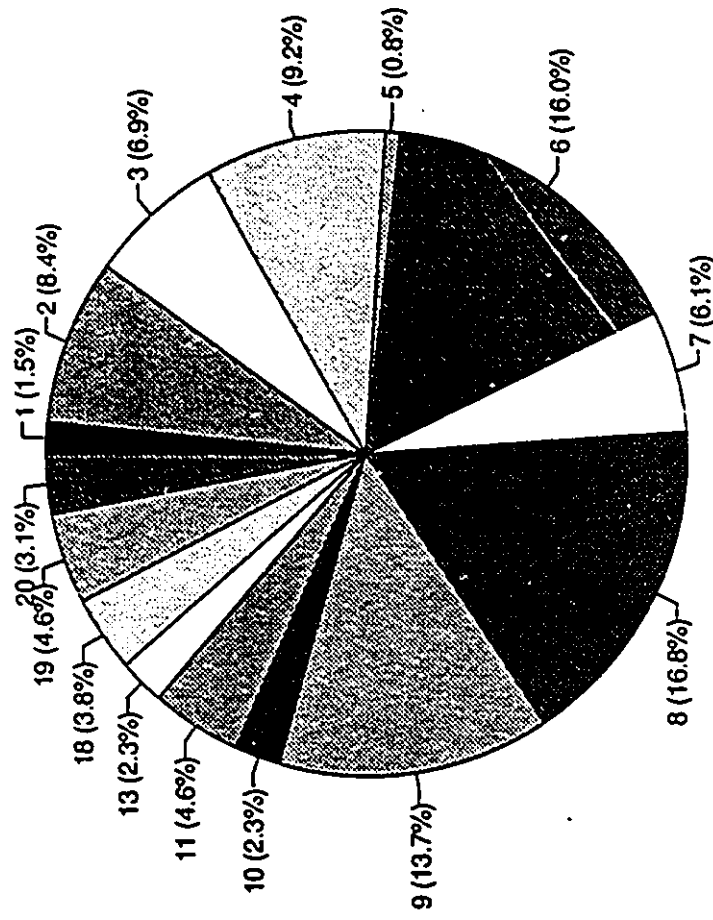


Figure 1.4
District Distribution
of Bridges Investigated

Table 1.1 Location of Ontario Regions and Districts

NAME	OFFICE LOCATION
Southwestern Region	London
Central Region	Toronto
Eastern Region	Kingston
Northern Region	North Bay
Northwestern Region	Thunder Bay
District 1	Chatham
District 2	London
District 3	Stratford
District 4	Burlington
District 5	Owen Sound
District 6	Toronto
District 7	Port Hope
District 8	Kingston
District 9	Ottawa
District 10	Bancroft
District 11	Huntsville
District 13	North Bay
District 14	New Liskeard
District 16	Cochrane
District 17	Sudbury
District 18	Sault Ste. Marie
District 19	Thunder Bay
District 20	Kenora

CHAPTER 2

ONTARIO MINISTRY OF TRANSPORTATION

BRIDGE MANAGEMENT POLICIES

The Bridge Management Section of the Ontario Ministry of Transportation is in the process of developing a Bridge Management System at a network level for the provincially-owned highway structures. This process has been a lengthy one with several stages of development. Established in 1985, the Bridge Management Section is a relatively new section of the Ministry.

For many years the Ministry relied heavily upon the experience and knowledge of its own personnel to prioritize rehabilitation needs and funds. Each Region would designate inspectors within their respective Districts to visually inspect bridges within the regional boundaries. These inspections included a visual inspection of all the elements of the structure and photographic documentation of the deteriorated areas. These were summarized in an inspection summary sheet. The inspections were conducted biannually so that progressive deterioration could be monitored. These inspections were used to develop a priority system for future repair contracts. However, this method of prioritization can cause problems if inspectors rate similarly deteriorated conditions differently. Furthermore, the future cost of repairing one structure versus another was not

taken into consideration. Before 1980, and in some cases since, some structures were rehabilitated because paving contracts were scheduled for the stretch of highway crossing the structure or realignments of the highway were scheduled. In some instances, rehabilitations were planned because it was considered more economical to repair structures in close proximity to one another at the same time. This method of prioritization proved not to always be the most cost effective. Some structures on highways of higher priority with higher levels of deterioration were not repaired and this led to further deterioration. In other cases, the deterioration increased to the extent that a more costly rehabilitation had to be implemented.

In 1986 the Ministry implemented the Ontario Structure Inspection Manual, OSIM (Reference 9), to standardize inspection methods, introduce rating systems for material and performance defects and to develop a computer inventory system incorporating all structural rehabilitation needs. In Part 1 of the manual, detailed descriptions of the different stages of material and performance defects of the various bridge components are defined and illustrated. Part 2 of the manual outlines the inspection rating systems used to assess material and performance defects for each component of the structure. Each component of the structures (ie., substructure, superstructure, concrete barrier walls, etc.) is assigned a rating between 1 and 6. A rating of 1 indicates that the component is in poor condition with severe material defects and in critical or inadequate performance condition. A rating of 6 indicates that the component is in like new material condition and is in very good performance condition. The entire range of ratings for material defects and performance condition, 1 to 6, are found in Figure 2.2 and Table 2.3 in Part

2 of OSIM respectively, see Appendix A, Figures A-1 and A-2.

These ratings are then used to determine the time period in which the structure will require repairs or rehabilitation. The ratings and the suggested time periods for rehabilitation are outlined in Table 1.3 of Part 3 of OSIM's (see Appendix A, Figure A-3).

A disadvantage to this system of prioritizing for rehabilitation contracts is that the level of service expected from the highway that crossed the structure is not taken into account and benefit/cost ratios for repairs are not considered. Furthermore, the level of service expected varies with location. For example, it would be difficult to compare the level of service required on the Burlington Bay Skyway to the level of service expected on a two lane highway in the northern part of the province which crosses a creek (culvert type structure). If the culvert received a performance rating of 2 and the Skyway received a rating of 3, the culvert would be chosen for rehabilitation prior to the Skyway. If a benefit/cost analysis was conducted the Skyway would likely be repaired in spite of the lower performance rating and further deterioration of the culvert. Currently the Ministry is adopting a new system which takes into account the material and performance ratings of the structure and a financial analysis comparing the various types of rehabilitation options is conducted. A present value analysis or an incremental benefit/cost ratio analysis is used to make decisions on which alternatives to choose at the project level for each structure. An incremental benefit/cost ratio is used at the network level within each Region in the Province as a whole, to make decisions amongst all the structures submitted by the five Regions that require repair or replacement. The addition of financial analyses

to aid in the decision making process, of which type of rehabilitation method to implement and which structure to rehabilitate, will enable both the Regions and the Head Office to make more economical and cost effective decisions. This financial analysis system is outlined in the Structural Financial Analysis Manual, Reference 26.

The present bridge management program spans five years, which corresponds to a performance rating of 4 for a structure which indicates repairs will be required in 3 to 5 years. Each Region is still responsible for biannual visual inspections to rate the condition of the structure under the 6 point system. Once fully operational, this new system will require each Region to conduct its own benefit/cost analysis to prioritize the structures requiring rehabilitation. The Region then decides which structures to recommend to Head Office to include in the Ministry's rehabilitation program. Head Office typically summarizes all Regional recommendations, and either agrees or disagrees with the types of rehabilitation methods proposed and to the urgency for action. Funds for the rehabilitation of all provincially owned structures are allocated through the Transportation Capital Branch of the Ministry.

At the project level, a detailed deck condition survey is conducted two years before any rehabilitation is undertaken. In Table 1.2, Part 3 of OSIM's, (see Appendix A, Figure A-3) a guideline is suggested for when bridge decks require detailed condition surveys based on the material condition rating (1 to 6) that the deck receives during the biannual inspections. Detailed bridge deck condition surveys are also required two years prior to a paving contract on the approaches to a bridge. A detailed bridge deck condition survey includes both visual and physical inspections of all components of the structure.

The Ministry has set guidelines as to how these surveys are to be conducted and documented. This information can be found in Reference 8, Structure Rehabilitation Manual, Part 1, Condition Surveys. The standard measurements of deterioration recorded in this survey are used to help select the most suitable repair method, calculate the removal quantities at the time of contract, and prepare the contract drawings. Briefly, a detailed deck condition survey involves visual documentation of all physical defects such as cracks (widths and types), spalls, surface delaminations, damp areas, and efflorescence stains/deposits on all exposed concrete surfaces. The condition of all expansion joints, bearings, and hand rails are also recorded. Concrete cores are extracted in order to visually assess the condition of the concrete deck. Some of these cores are later tested in the laboratory to determine specific properties of the deck concrete and the extent of deterioration. If more than four years pass before the structure is rehabilitated a second condition survey must be conducted.

There are several factors which influence the priority for repair and the selection of the repair method:

- location of the structure and its importance in the highway network. Traffic volumes, size of structure, importance of the highway, accessibility of detour routes and impact of lane closures on traffic flow are all contributing parameters in determining the importance of the structure
- type and geometry of the structure
- nature of deterioration, type, location, extent and the causes of the deterioration
- projected service life of the structure

- load carrying capacity of the structure
- cost of repairs and availability of funds
- future reconstruction program. This effects the timing of the rehabilitation as most rehabilitations are scheduled in conjunction with highway improvement contracts
- local experience and contractor expertise
- social and environmental concerns such that the inconvenience to the public is kept to a minimum.

Higher priority is given to certain structures like thick slab structures and some box and tee girder bridges where the deck is an integral part of the main structural members. Approximately 9% of the bridge decks used in this thesis fall into this category. Tables 3.1 through 3.3 of the Structure Rehabilitation Manual, Reference 8 (see Appendix B, Figures B-1, B-2, B-3), outlines the technical considerations in the selection process for repair and rehabilitation contracts. These tables summarize the different defects and deterioration usually found in concrete structures and the alternative methods for repair and rehabilitation that are most appropriate for each.

Physical testing is conducted so that an accurate assessment of the internal concrete deterioration can be made. On asphalt covered decks, sawn asphalt sample areas are removed and the conditions of the waterproofing layer, concrete deck surface, and asphalt are recorded. Concrete cover to the reinforcing steel is measured by taking pachometer readings in the area of the removed asphalt. Concrete cores are also removed from the deck and the visual quality of the concrete, including any defects, are recorded. For exposed concrete deck surfaces concrete cover pachometer readings are taken at each intersection of the grid laid out on the deck surface in addition to the tests conducted on

asphalt covered decks. Also, a delamination survey is conducted using the chain drag method. Some of the cores removed are assessed for compressive strength, air void distribution and chloride content.

2.1 Compressive Strength

Compressive strength is measured to assess the quality of the concrete. A 28 day strength of 30 MPa is presently specified for all newly constructed bridge decks. Several structures included in this study had compressive strengths between 20 and 30 MPa.

2.2 Air-Void Content

The air-void content test is conducted in order to estimate the adequacy or existence of air entrainment in the concrete (Reference 3, ASTM C 457-82a). If this test indicates an air content exceeding 3%, a spacing factor less than 0.20 mm, and a specific surface exceeding $24 \text{ mm}^2/\text{mm}^3$, the concrete is deemed to have been properly air entrained at the time of construction.

2.3 Chloride Ion Content

The third test conducted on the concrete core samples is the chloride ion content test. This test measures the depth at which chloride ions have penetrated into the concrete at the time the sample was removed. Since 1979, the "water-soluble chloride ion content test" has been used to measure the chloride ion content at various depths from the surface of the concrete core. The water-soluble chloride content is defined as the amount of

chloride which is extractable in water under specified conditions. The chloride threshold value necessary to depassivate the reinforcing steel layer, initiating corrosion, is defined to be 0.02% by mass of concrete (concrete with a cement factor of 300 kg/m^3) or 0.15% by mass of cement content. Most decks requiring repair have surpassed the threshold value for chloride ion concentration. In the fall of 1990, the Ministry changed the testing procedure requirements for the chloride content to the acid-soluble chloride content. This test method measures the amount of chloride that is soluble in nitric acid. This test is more reliable than the water-soluble test for estimating chloride ion content at different depths from the concrete surface of the extracted cores.

2.4 Electrochemical Testing

Electrochemical testing is also conducted during detailed deck condition surveys. This involves the use of a copper-copper sulphate half-cell as discussed in Chapter 4. The cell measures the probable corrosion activity of the reinforcing steel at the time of testing. This test is carried out in accordance with ASTM C 876-87 (Reference 4). The other half of the cell is the reinforcement and the concrete. When connected, these two cells form a complete electrical cell which generates a potential that is measured with a high-impedance millivoltmeter. These readings are taken at the intersection points of a grid pattern laid out on the bridge prior to the beginning of the test in accordance with Reference 8. When the test is completed, the results are plotted on the grid system and potential contours are drawn around the points measured to form a "potential" map of the corrosion of the reinforcing steel.

Potential measurements do not indicate the rate of corrosion. Rather, they measure the probability that the reinforcement is actively corroding at the time the measurements were taken. A good ground connection directly connected to the reinforcing steel or to a component that is in direct contact with the reinforcing steel is essential. The surface of the deck must be dry at the time of testing but not so dry that the passage of current to the reinforcing steel is inhibited. To maintain a constant potential drop through the concrete portion of the circuit, an electrical contact solution is used to wet the concrete surface and the conductive end of the probe. Chapter 4 outlines the accepted interpretations of these test results.

The measurements obtained from this procedure are generally reliable but the results are influenced by temperature, a reliable ground to reinforcement being obtained, and a continuous circuit in the layer of reinforcement that is being tested. In the author's opinion, the reliability of the corrosion potential also depends on the experience of the individual conducting the test. The Ministry published the findings of a 1988 study (Reference 17), which compared the removal of deteriorated concrete areas during rehabilitation contracts to the areas denoted as undergoing active corrosion during the previously conducted detailed deck condition surveys (more negative than -0.35 V cse, cse denotes testing results from a copper-copper sulphate half-cell). The study demonstrated that there was good correlation between the delaminated concrete areas and the areas with high corrosion potential. The study indicated that areas with potential measurements more negative than -0.35 V cse represented areas of the deck which contained corroding reinforcing steel. However, composite concrete-timber decks showed

poor correlation between the actual areas of deterioration at the time of rehabilitation and the predicted areas of deterioration measured during the detailed condition survey. This discrepancy was attributed to the fact that this type of deck has only a single layer of nominal reinforcement with usually inadequate concrete cover.

Recently, the Ministry introduced another stage to predict which structures would require a detailed deck condition survey. This new step involves the use of radar-waveforms to detect faults in the deck. This test method is referred to as a "DART" survey. This survey is conducted prior to the detailed deck condition surveys and is used in the decision-making process to determine which structures to add to the rehabilitation program. The DART involves analyzing the readings taken by an impulse radar with a computer (Reference 6). By analyzing the differences in the amplitudes of the peak excursions, delaminations, debonding and scaling of the concrete surface, concrete cover to the reinforcement, and asphalt thickness can be measured.

CHAPTER 3

DETERIORATION STUDIES

Numerous papers address the development of bridge management systems (BMS) and the service life of several types of rehabilitation methods but few concentrate on methods in which the service life of a bridge may be estimated. At the Fifth Annual Workshop on Bridge Management Systems titled "Bridge Deterioration Rates and Models" held in Washington, D.C., on January 13th 1991, some papers were presented that relate to this thesis (References 16 and 20).

In Reference 5, a bridge management system is defined:

A bridge management system (BMS) is a rational and systematic approach to organizing and carrying out all the activities related to providing programs for bridges vital to the transportation infrastructure. The activities include: (1) predicting bridge needs, (2) defining bridge conditions, (3)....(10) monitoring and rating bridges, and (11) maintaining an appropriate data base of information. A BMS should assist decision-makers at all bridge management levels to select optimum solutions from an array of cost-effective alternatives for every action needed to achieve the desired levels of service within the funds allocated and to identify future funding requirements.

This thesis concentrates on the monitoring and rating of bridges in reference to the potential of the reinforcing steel embedded in a concrete bridge deck to corrode to the

extent that deck rehabilitation is required. The data collected and analyzed in this thesis fulfil the requirements of the historical data analysis module of a BMS. Predicting deterioration rates will decrease errors and improve reliability in estimating the type of rehabilitation that should be implemented. It will also help improve the accuracy of the cost/benefit ratio comparisons of performing rehabilitations on one structure versus another. A good BMS meets the following objectives:

- improves the type and quality of the data collected as well as the way it is stored, managed, and used in the analysis
- supplies a logical method for setting priorities for current needs
- permits reliable and realistic forecasts of future needs to be made
- fosters changes in management ideology and goals.

In Appendix D of Reference 27, the authors discuss the bridge management systems currently in place in the United States. In 1987, California, Illinois, Maryland, New Mexico, New York, North Carolina, Pennsylvania, Texas, and Wisconsin had bridge management systems. Some of these systems were still in their early stages while others were advanced and fully operational. It should be noted here that the American deterioration condition rating system differs from the Canadian system. The Federal Highway Administration (FHWA), the governing federal body in the United States, uses a 9 point rating system. A rating of 9 represents no deterioration and a rating of 3 recommends deck replacement. However, New York uses a 7 point rating system where a rating of 0 means the structure is fully deteriorated and a 7 represents no deterioration. Each State has adopted the FHWA's recommendations and has developed their own system of applying weights to the different components of the bridge as a way to

prioritize rehabilitations. All of the American studies referenced used a numerical rating as a quantitative measure of the deterioration of the structures in the development of their respective deterioration curves.

Reference 20, summarizes deterioration studies conducted in the United States up to the end of 1989. It is understood that this report will be updated in the near future. The objective of this report was to supply guidelines for bridge management systems so that sound, cost-effective, and consistent decisions set the priorities and options for the rehabilitation of American highway bridges. In each case, "rate of deterioration" is calculated from the historical data available. The report referenced devotes an entire chapter to bridge service life prediction models. It emphasizes the importance of estimating the remaining bridge service life and the life expectancy of maintenance and rehabilitative measures as a part of the decision-making process for fund allocation for present and future rehabilitation projects.

3.1 Service Life

To gain full advantage from any set of deterioration curves, the definition of "service life" and the parameters that measure service life must be defined. Service life can be defined as the time it takes for the performance indicator of a bridge component to reach its "unit failure". The magnitude of the performance indicator that represents the need for rehabilitation is referred to as the "unit failure". Performance indicators are physically measured forms of deterioration such as delaminations and spalls on an exposed concrete deck. An example of this would be how the Ministry uses specific

percentages of the deck surface area that have undergone spalling and delaminations as part of the decision process for the type of rehabilitation to use on a deteriorated deck (see Appendix B, Figure B-4).

In Reference 20 service life is defined in three ways. The "useful life" is defined as the number of years a bridge serves before it becomes structurally inadequate or unsafe. The "functional life" is defined as the number of years before a bridge becomes functionally obsolete. The third definition, "economic life", is the number of years before replacement becomes more cost effective than continued rehabilitation and maintenance, taking into account life cycle and user costs.

3.2 Summary of Deterioration Studies

All of the studies summarized aided in setting the basis for the analysis conducted in this thesis.

3.2.1 Factors Influencing Deterioration

The factors outlined in several of the reference studies which influence the length of a structures service life are as follows:

- 1/ age of the structure
- 2/ quality of design
- 3/ quality of construction
- 4/ environmental conditions and
- 5/ external influences such as traffic volumes and/or the use of de-icing salts.

In Reference 20, deterioration curves are presented by the Transportation Systems Centre (TSC), Massachusetts Institute of Technology (MIT), Wisconsin Department of Transportation (WisDOT), New York State Department of Transportation (NYSDOT) and the Federal Highway Administration, Demonstration Projects Division (FHWA). In the study by the TSC, the influence on deterioration of several independent variables was assessed. Age, traffic volumes, location (State), type of bridge, maintenance records, number of spans and skews were all considered. All of the studies referenced reviewed the factors which influence deterioration. Little variation was found in those factors listed in References 7, 12, 16, 20, 21, 23, and 27. Age is undoubtedly the most important factor with strong correlations. Traffic volume was noted as the second important influence. These were common results in all the studies referenced.

3.2.2 Method of Analyses

Data was eliminated from these studies if data entries were implausible or if some of the information was missing. Linear regression analysis techniques were used in five of the nine studies. The MIT study incorporated a single binary linear probability method of analysis. This analysis depicted the non-linear relationship between age and deterioration. A drawback to this study was that it did not use the condition rating of the structures analyzed as the dependent variable but instead used a probability between 0 and 1 that a specific condition rating would occur. This makes the results difficult to interpret.

Three of the studies used a piece-wise approach in their regressions. Piece-wise

regression analysis involves separating the data according to their scatter and developing separate regression lines for each group. These separate lines were then connected in segments of straight lines which resulted in different rates of deterioration for the varying group separations.

The calculated correlation coefficient for most of these regression studies was quite high, between 0.6 and 0.8. These good correlations are most likely due to the large number of structures included in the studies. The numbers were significant enough to develop deterioration trends with fairly good confidence. The number of the structures analyzed in each study far exceeds the number of structures available for analysis in this thesis. The TSC and MIT studies involved 151,933 bridges and in the WisDOT study 4,463 bridges were included. The majority of these studies forced the y-intercept of the regression analysis to the value representing no deterioration at the time of construction.

In Reference 16, the New York State Thruway Authority (NYSTA) developed a computer-aided bridge needs project system (CABNPS). The rate of bridge deck deterioration was established by using data collected from biannual surveys in the following empirical equation:

$$DR_i = d_r(t_i)/d_t = (r_i - r_j)/(t_i - t_j) \quad (3.1)$$

where DR_i = deterioration rate
 r_i = rating at time t_i
 r_j = rating at time t_j

The rating values ranged from 1, fully deteriorated, to 7, no deterioration. Average DR_i 's were calculated for each possible condition rating. For example, for all the bridge decks

which initially received a condition rating of 5, the sum of the numerical values of their individual rating changes (Δr) was divided by the sum of the time periods involved (Δt), which yielded an average DR for bridges rated a 5. This process was repeated for each possible rating (1 through 7) and a series of system average DRs were calculated. The inverse of DR represented the time required for a bridge deck to change by one condition rating. The cumulative total of the inverse of DR for each individual rating was then plotted and a system population average deterioration curve was developed.

A Swedish study also took the approach of developing an empirical formula (Reference 21). The following equation was developed for estimating a bridge deterioration index (B_{DI}):

$$B_{DI} = AFSTP/100 \quad (3.2)$$

where A = average age of bridges incorporated in the study, study conducted on all city owned bridges in several Swedish cities
 F = number of freeze-thaw cycles per year
 S = amount of de-icing salt spread out per year
 T = traffic volume in total amount of vehicle-kilometres per m² street area
 P = percentage of bridge deck area constructed before 1965.

The reason for the 1965 separation is that prior to 1965 air-entrainment was not used in typical concrete construction. Also, the pre-1965 water/cement ratio was 0.6 whereas after 1965, it was decreased to 0.5. These factors would significantly increase the durability of the concrete with respect to its resistance to freeze-thaw cycles. In the concluding remarks of this report it is suggested that for decks experiencing problems with reinforcement corrosion, the parameter P may be redefined as the critical age or

service life expected for deterioration due to corrosion.

The two Canadian studies referenced did not use regression analysis to assess data. In the Alberta study, (Reference 7) deterioration was measured by the percentage of the deck area which contained cse readings more negative than -0.35 volts. This test method is explained in detail in Chapter 4. This thesis used this method for measuring corrosion. The deterioration expressed as a percentage of deck area was then plotted against the age of the structures.

The second Canadian study took a different approach in estimating deterioration of bridge decks. This paper was presented at the International Conference on Short and Medium Span Bridges held in Toronto, in 1982 by the Ministry's Materials Office. In this report, a condition rating (CR) was assigned for the concrete bridge decks surveyed. The CR values (1 to 6) represented a timeframe for replacement or rehabilitation based on the deterioration described in the general condition survey conducted for each individual structure. If the CR was equal to 1, the deck required replacement. A CR of 3 indicated the need for rehabilitation within three years while a CR value of 6 indicated that a rehabilitation was not required. The CR values assigned to the bridge decks were based on the assumption that slabs with the most serious deterioration should be rehabilitated first. This is not always the case as the benefit/cost analysis may indicate that for the more seriously deteriorated structures it would be more economical to let them deteriorate until a full deck replacement is required.

3.2.3 Summary of Significant Findings

Although the results of each of these studies varied somewhat, they share some common conclusions.

3.2.3.1 TSC Study

The TSC study indicates that skewed decks deteriorate more quickly than non-skewed decks and that multi-spanned decks deteriorate more quickly than single span decks. It was also noted that the type of wearing surface influenced the rate of deterioration. The decks protected with asphaltic concrete and a waterproofing membrane deteriorated slower than exposed concrete decks and asphaltic concrete covered decks without waterproofing membranes.

3.2.3.2 WisDOT Study

The WisDOT study used the piece-wise method of regression analysis and concentrated on comparisons of the condition rating between 0 and 9 to the age of the structure. The study concluded that deterioration increased by 0.07 points (9 point rating system) per year between ages 1 to 25 years. The slope of the regression line flattened out between 26 and 45 years of age. Deterioration began to increase after 45 years of age by 0.19 points per year. This study also included separate curves for the different bridge types surveyed. These curves shared similar shapes indicating similar vulnerability to deterioration.

3.2.3.3 NYSDOT Study

The NYSDOT study also used piece-wise regression analysis. A rate of deterioration was estimated by plotting the condition rating versus age for two inspection cycles spaced two years apart. Deterioration increased in this two year span as shown by the later, second curve, which plotted to the left of the first curve. This indicated an average drop in the condition rating of 0.122 condition points per year. For these curves, the y-intercept was forced to 7. It should be noted here that the condition rating axis ascends up the y-axis with the undeteriorated condition at the top of the axis.

3.2.3.4 FHWA Study

A piece-wise regression analysis was used in this study. The results indicated that the average deck condition declined at a rate of 0.104 condition points (9 point system) per year for the first ten years and then slowed down to 0.025 condition points per year for the remaining years. Maintenance and rehabilitations were not identified in this study, which is possibly the reason for the significant drop in the deterioration rate after some ten years of service.

3.2.3.5 Dunker and Rabbat Study

Dunker and Rabbat used 296,668 structures from the U.S. National Bridge Inventory to undertake their study (Reference 12). They reported that climate, environment, and traffic volumes did not have a major influence on the deterioration of the structures analyzed. Dunker and Rabbat suspected that local de-icing applications,

design and construction practice and maintenance programs, and funding were the reasons for this observation.

The bridges were separated into twelve different "type" categories, and it was found that the timber stringer type structures were the most deficient. It was also observed that continuous structures showed better performance than simple supported structures. Dunker and Rabbat concluded that timber stringer type structures performed the worst and prestressed concrete slab or stringer and continuous reinforced concrete slab or concrete tees performed the best.

3.2.3.6 CABNPS Study

The deterioration curves developed in the CABNPS study indicated that deterioration increased exponentially with time. The curve was S-shaped with an increase in the rate of deterioration beginning after 5 years of service, coincident to a deck condition rating of 5.5. The curve indicated that after 30 years of service, the average bridge condition rating would drop to a rating of 1. The bridge would then be closed and replacement would be recommended. This rating was attained as early as 20 years in the curves representing the ranges of deterioration for the individual decks. This report emphasizes that the curves developed can only be considered to represent the average for the thruway structure bridge population.

3.2.3.7 SNRA Study

The resultant bridge deterioration indexes calculated (B_{DI} from equation 3.2) in the SNRA (Swedish National Road Administration) study varied from 3.7×10^6 in the city of Solna to 55.1×10^6 in Stockholm. These values were then input into another empirical equation which estimated the annual bridge maintenance cost index:

$$B_{MCI} = 83.4 \sqrt{(\log B_{DI} - 6.45)} \quad (3.3)$$

The units of measure for the B_{MCI} are in Swedish Kronor/m² of bridge deck. This equation was used to aid in the financial planning of operational and maintenance budgets of the specific cities included in the study.

3.2.3.8 Carter Study

The deterioration curve developed in the Carter study was S-shaped and depicted a deterioration rate between eight and ten percent per year after more than 20 percent of deck area had corrosion potential readings more negative than -0.35 volts. This level of deterioration was reached after some 15 years of service. It should be noted that all of the structures included in this study were built before 1975, not protected with a waterproofing membrane at the time of construction, and are located on the primary highway system (highly salted sites) in Alberta.

3.2.3.9 MTO Study

In the MTO (Ontario Ministry of Transportation) study, the condition ratings assigned to the 642 bridge decks were proportionately extrapolated (within each Region)

to the entire population which indicated that 360 bridge decks would require replacement or rehabilitation within one year and 1356 within five years. This represents a need to rehabilitate 249 bridges/year over four consecutive years. This number of bridge decks could not possibly be rehabilitated as funds are not available. The report concluded that bridge decks on Ministry owned highways exhibit significant deterioration. Unfortunately, this study made no allowance for the increased deterioration of decks with time and it made no comparison of the measured deterioration to time.

CHAPTER 4

CORROSION PROCESS OF ONTARIO BRIDGE DECKS

The main cause of deterioration of Ontario bridge decks is the corrosion of the reinforcing steel due to the penetration of chlorides at concentrations in excess of the threshold value where corrosion is initiated. This chapter describes the corrosion process, the factors which influence it and the methods used in Ontario to measure corrosion of existing bridge decks.

4.1 Corrosion of Steel in Concrete

Corrosion is defined as "the degradation of a material by reacting with its environment" (Reference 27). The material most commonly referred to when discussing corrosion is steel. Corrosion can occur by either wet or dry reactions. Dry corrosion of reinforcing steel takes place in the presence of oxygen. The iron and oxygen ions react at the surface of the reinforcing steel resulting in the formation of an oxide layer. This oxide layer varies from a brown rust layer which is formed at ambient temperatures to a three-layered millscale which forms at high temperatures followed by a cooling period. The formation of these oxide layers hinders the oxygen from penetrating the surface of

the steel. Thus, the rate of reaction is slowed as the layers increase in thickness. These oxide layers generally make the reinforcing steel passive prior to placement in a concrete structure.

The process of corrosion of metals in solution under the influence of a self-induced electrical current is known as wet, or electrochemical corrosion (galvanic corrosion). For the electrochemical reaction to occur, a flow of current from an anode site, where oxidation of the metal takes place, to a cathode site, where a reduction takes place, is required. The reactions at the anodes and cathodes are called "half-cell reactions" and may occur at different locations along the same length of a reinforcing bar. The reaction taking place at the anode is known as oxidation: $\text{Fe} \rightarrow \text{Fe}^{++} + 2\text{e}^-$. The electropositive ferrous ions pass into solution in the electrolyte while the electrons remain in the steel bar and migrate to the cathode site. At the cathode consumption (reduction) of the electrons released at the anode occurs: $2\text{H}_2\text{O} + \text{O}_2 + 4\text{e}^- \rightarrow 4\text{OH}^-$. The electrons react with the oxygen present in the electrolyte and produce electronegative hydroxyl ions. Both oxygen and water must be present for the anodic and cathodic reactions to develop. These reactions will continue as the oppositely charged Fe^{++} ions and the 4OH^- ions react to produce ferrous hydroxide, $\text{Fe}(\text{OH})_2$, (better known as "rust"). Rust is insoluble in water and is precipitated at some point between the anode and the cathode sites. This rust does not offer any protection to the reinforcing steel and its increased volume develops expansive pressures in the concrete surrounding the steel.

The corrosion process is relatively slow in water that does not contain dissolved salts. When sufficient quantities of soluble chloride ions are present in the water, its ionic

concentration, and thus its electrical conductivity, increases. In this case, the corrosion process in the presence of oxygen is much faster. In a concrete environment, the pore water is highly alkaline and it contains readily available hydroxyl ions for the reaction to continue. The high alkaline environment is created when the cement is mixed with water and the calcium silicates react to form the alkaline byproducts of sodium, potassium, and calcium hydroxides. A protective layer or passivating film of either ferrous hydroxide or lime-rich iron oxide forms on the surface of the steel when it reacts with the alkaline pore water, pH greater than 12.5. When chloride ions penetrate the concrete, they reduce the alkalinity of the pore water such that the passive layer surrounding the reinforcing is destroyed. Once the passive layer is destroyed, the reinforcing steel will corrode in an electrochemical manner in the presence of both water and oxygen. The reaction of the steel with the chloride ions forms either FeCl_2 , FeCl^+ or FeCl_3^- ions. It has also been postulated, (References 13 and 19) that the iron chloride complex reacts with the hydroxyl ions and forms ferrous hydroxide and chloride ions. The use of de-icing salts on bridge decks will increase the amount of chloride ions in solution, which in turn, increases the risk of corrosion of the deck reinforcing.

As reinforced concrete is not a homogenous material, electrical potential differences can occur between areas with different moisture contents or concentrations of oxygen, areas where cracks have evolved, or in areas with different residual stresses in the steel. Therefore, a bridge deck may contain several different sites where anodic and cathodic reactions are taking place.

Another mechanism which encourages the corrosion of reinforcing steel is

"carbonation". Carbonation occurs when carbon dioxide gas dissolves into solution and reacts with the hydration products of cement to form calcium carbonate. In the formation of calcium carbonate, calcium hydroxide is depleted. This lowers the relative Ph or alkalinity of the concrete. Reinforcing steel located within this layer of carbonated concrete will no longer be protected and corrosion of the steel in the presence of water and oxygen is highly likely. Carbonation is not normally a problem in Ontario concrete as high quality cement, low water/cement ratio mixes are used and relatively low levels of carbon dioxide pollution are present in Ontario's environment.

4.2 Factors Influencing Corrosion

Several factors influence the development of corrosion: age, quality of concrete, concrete cover to the reinforcing steel, nature of the environment, and design and construction practices.

4.2.1 Quality of Concrete

4.2.1.1 Portland Cement

Portland cement offers an alkaline environment which protects and pacifies embedded reinforcing steel. The use of some blended cements may prove to be damaging because they can cause a reduction in the alkalinity of the final concrete product. However, the use of blended cements can reduce concrete permeability and increase the electrical resistivity when the water/cement ratio is lowered. The reduction in

permeability of concrete may be great enough to increase its resistance to chloride penetration by five times when blended cements are incorporated in the mix as opposed to the use of plain portland cement. The permeability of the concrete is one of the most important characteristics in preventing the egress of chlorides to the level of the reinforcing steel. The most effective way to control permeability is to limit the water/cement ratio. Through experiment, (Reference 22) it was found that a concrete with a water/cement ratio of 0.40 combined with a concrete cover of 40 mm successfully prevented corrosion of reinforcing steel after 800 applications of salt. When 70 mm or 90 mm of cover were used, the water/cement ratio could be increased to 0.50 and 0.60 respectively in order to obtain the same value of corrosion protection. A low water/cement ratio reduces the porosity of the concrete while increasing its strength.

Tricalcium aluminate (C_3A), a component of portland cement can react with diffusing chlorides through a chemical binding process and reduce the amount of "free chlorides" available for depassivation. The amount of tricalcium aluminate in the concrete is a function of the type of cement used. Referring to Mehta's research, (Reference 25) for the chemical binding of penetrating chlorides to occur, the content of C_3A must be greater than 8%.

4.2.1.2 Aggregates

Aggregates used in concrete mixes should be free from chloride salt contamination. Contamination is likely when sand is dredged from the sea or arid locations. When concrete is mixed, care should be taken not to use admixtures which

contain chlorides. Porous aggregates, usually used when mixing lightweight concretes, are noted for their ability to absorb large quantities of salt.

4.2.1.3 Water

If the moisture content is high, the diffusion rate of carbon dioxide will be substantially reduced which reduces the rate of carbonation of the concrete. It has also been found, experimentally, that the process of gradual drying of initially water-saturated concrete may possibly increase its electrical resistivity to the point where corrosion is negligible. This level of electrical resistivity is approximately 50 to 70×10^3 ohm-cm (Reference 1). Concrete with a low permeability and low porosity allows less water to enter or remain in the concrete. Therefore, this concrete will likely have a low electrical conductivity, and it will also better resist the penetration of salts.

4.2.1.4 Admixtures

The use of chemical admixtures to inhibit the corrosion process has not been too successful. Some admixtures have side effects such as low strength, erratic setting times, efflorescence, and an increased incidence of alkali-aggregate reaction (References 1, 25 and 28).

4.2.2 Rate of Chloride Penetration

The three stages of corrosion are as follows:

- ingress of chloride ions until the critical chloride concentration is reached

- corrosion of steel at a constant rate until the expansive forces induced on the concrete by the volume of the corrosion products (rusted rebar takes up more volume than an unrusted rebar) causes cracking and the eventual delamination of the concrete
- the corrosion rate is increased due to the increase in the oxygen supply through the deteriorated concrete.

Reference 2 noted that it is difficult to estimate when concrete containing actively corroding steel will crack. The time to delamination is approximately 1 to 5 years after the corrosion process begins. The exact timing is dependent on concrete cover and other factors such as the permeability of the concrete and external temperatures. It is estimated, that corrosion rates double for every 10 °C temperature increase above 10 °C. At low temperatures, the corrosion rate diminishes to almost zero. For this reason, in warmer climate regions like Florida, which is also a high chloride moist environment, corrosion rates are much higher than in Ontario. It could be assumed that corrosion rates in the Southern Region of the province are higher than corrosion rates in the Northwestern Region where there is lower relative humidity and cooler temperatures. This is discussed further in Chapter 6.

Another factor affecting the rate of corrosion is the resistance of the electrolyte, which is affected by the composition of the pore water within the concrete. The rate of corrosion is a function of the cell current between the anode and the cathode. The cell current is a function of the potential and the combined resistance of the electrolyte and the connecting steel. Significant corrosion of the reinforcing steel only occurs when the resistivity of the concrete is less than approximately 10,000 ohm-cm^{2.5}.

4.2.2.1 Initial Phase

In Reference 30, Slater refers to experiments which determine the chloride threshold level at which the breakdown of the passive film on the steel occurs. This level was found to be directly related to the amount of cement used in the concrete mix. The experiments suggested 0.025% to 0.035% of chloride by weight of concrete as the threshold value for a cement content of 350 kg/m³. These experiments suggest there is a threshold value for chlorides at the level of the reinforcement which must be met in order for corrosion to take place. Several of the other reports referenced also conclude that the rate of chloride penetration is a function of the water/cement ratio. Therefore, the diffusion rate of chlorides ions should be inhibited as much as possible.

The presence of varying levels of diffused oxygen and chloride ions at different sites within the concrete establishes differential cells referred to as "microconcentration cells". These cells begin the corrosion process once the chloride threshold level is exceeded. If the concrete undergoes drying, the pH at the anode is lowered. When further cycles of moisture/oxygen occur, this lower pH allows the corrosion process to continue. However, this initial corrosion is not the primary damaging mechanism. The formation of "macrocells" induces corrosion at a much greater rate.

4.2.2.2 Propagation Phase

Macrocells are created within the concrete between areas of different concrete covers, different pH levels of the attacking solution, and where different concentrations of chloride ions initiate corrosion of the reinforcing steel due to variations in the quality

of the concrete. The controlling reaction at the cathode is the reduction of oxygen. Therefore, oxygen diffusion to the cathodic sites is a major factor influencing the propagation time of corrosion. It is highly likely that most reinforced concrete structures contain two different depths of reinforcing steel which are electrically connected. Furthermore, it is highly probable that two different concentrations of chloride occurs at these two depths. This also creates a macrocell (active/passive cell). A similar circuit is developed when coated reinforcing steel is connected to and in close contact with uncoated steel. In this case, corrosion occurs at breaks in the coating. This circuit can contain large driving voltages and large cathode to anode ratios which will accelerate the rate of corrosion of the steel. This macrocell theory is supported in experiments referenced in Reference 30.

4.2.3 Concrete Cover to Reinforcing Steel

The concrete cover to the reinforcing steel offers more than a linear amount of protection. In Reference 19, Hope postulates that the diffusion of chlorides follows Fick's diffusion law:

$$\delta C / \delta t = D_c \delta^2 C / \delta x^2 \quad (4.1)$$

where C = chloride ion concentration at a distance "x" from the concrete surface after time "t"

D_c = chloride diffusion coefficient
 = 0.1×10^{-8} to 10×10^{-8} cm²/sec for w/c of 0.4 to 0.7 respectively

Under application of Fick's law, the depth of concrete cover to the reinforcing steel must be increased by a factor of approximately 2 for each order of magnitude increase in the

diffusion coefficient: for it to take the same amount of time for the chlorides to reach a specific concentration level.

A similar observation is made in Reference 27. This report states that corrosion varies with the square of the clear concrete cover to the reinforcing steel and furthermore, that corrosion protection increases with the ratio of the clear cover to the bar diameter (C/D). In Reference 27 it is assumed that good protection is provided when the C/D ratio is equal to or greater than 3.0.

4.2.4 Environment

The physical environment in which concrete is to be used is a key factor in estimating its potential to corrode. The use of de-icing salts on highway bridge decks for maintenance makes for an aggressive environment in Ontario. If concrete is continuously saturated, it will be protected from corrosion through a lack of oxygen. However, on the Ontario highway system only the foundation of a bridge may possibly be continuously saturated. The intermittent snow storms and use of de-icing salts before, during, and after a storm create an ideal environment for corrosion to take place. Not only is the chloride ion in a soluble state, but cycles of wetting (where moisture is supplied) and cycles of drying (where oxygen is supplied) occur.

Orientation is another environmental factor. As a bridge deck is horizontally oriented, there is more time for water and chloride ions to penetrate as snow and de-icing salts build up on the surface.

Cyclic loading, including fatigue and impact, and the environment supplied for the

reinforcement, are also considered as environmental factors. The internal environment supplied for the reinforcement is sometimes congested as minimum deck thicknesses are used. This internal space is shared with cables, anchorages and usually two mats of reinforcing steel (four layers). This results in minimum concrete cover protecting the reinforcement. Combined, the above conditions make the bridge deck's environment very severe.

4.2.5 Design and Construction

4.2.5.1 Design

Design practices should incorporate adequate cover, increased concrete permeability by specifying low water/cement ratios, and good quality high strength concretes, to inhibit early deterioration.

4.2.5.2 Construction

Faulty construction practices are noted as one of the most common causes of early deterioration (Reference 2). Construction faults such as inadequate compaction, improper placement of reinforcing steel, and the use of poor quality, high water/cement ratio concretes which result in an inadequate protection for the reinforcing steel. Surface finishing can also contribute to early deterioration of a bridge deck. Excessive trowelling of the surface and improper vibration of the placed concrete can lead to surface bleeding. This creates a brittle thin layer at the deck's surface consisting mainly of the cement paste

which is easily delaminated. These faults can result in corrosion of the reinforcing steel in almost any environment after the passive layer surrounding the steel is de-passivated.

4.2.6 Chloride Contamination

There are two common sources of chloride contamination in concrete. Chlorides can be added to the concrete through the mixing process itself or applied externally and diffuse down to level of the reinforcing steel. In Reference 30, researchers concluded that up to a certain level, chlorides present during the curing process can be absorbed by combining with the tricalcium aluminates to form insoluble compounds. Chlorides added to the mix will also be relatively uniformly dispersed and thus have a smaller tendency to create a concentration cell. In Ontario, the Ministry provides and enforces the use of contract specifications to control the types and amounts of admixtures, aggregates, cement, and all aspects of the concrete mix design to ensure that good quality concrete is placed in all of its structures. For this reason, internal sources of chlorides are not usually a problem.

When the chloride penetrates from external sources, uniform concentrations will not exist at the level of reinforcement as discussed in Section 4.2.2.2. Different concentrations of the chlorides exist at the surface as a result of either poor drainage, uneven concrete surface finishing, or snow being piled up along the curb line throughout the winter months. This latter practice causes a build up of moisture and a much higher concentration of de-icing salts along the curb line. When warmer temperatures arrive, this combination of ice, snow, and de-icing salts melts and corrosion will (undoubtedly) occur.

4.2.7 Epoxy Coated Reinforcing Steel

The use of epoxy coated reinforcing steel as a means of protecting the reinforcing steel from corrosion due to chloride ion penetration is a cause of concern. The epoxy coating offers a stable, impermeable coating which prevents the egress of both moisture and soluble chlorides. However, the amount of damage the bars suffer during transportation and storage at the site (ie., cuts and nicks in the coating exposing uncoated steel) before they are incorporated into the structure is a problem. It is thought that these small cuts and nicked areas will increase the intensity of corrosion in the bar. Experiments to test this theory concluded that the damage due to transportation and storage does not effectively increase the intensity of corrosion of epoxy coated bars. However, the electrical coupling of an uncoated and coated mat in a deck can induce accelerated corrosion. This appeared only to be the case when the area of defects in the coating exceeded 0.24% of the coated steel. It was also noted that when a waterproofing membrane was used in conjunction with the epoxy coated steel, the protection offered by the epoxy coating was extended considerably as the chloride penetration time to the reinforcing steel was increased.

4.3 Types of Deterioration due to Chloride Penetration

Some concrete deterioration has been linked to the penetration of chloride ions. Delamination and spalling are two of the most common types of deterioration due to chloride penetration. Cracks are not caused by chloride ion attack but they do assist in the deterioration due to chloride ions.

4.3.1 Cracking

Cracking is characteristic of all concrete because it goes through large volume changes with changes in the relative humidity and temperature (shrinkage cracking). As well, concrete has a very low resistance to tensile stresses and strains. Map or pattern cracking is generally caused by the use of reactive aggregates in the concrete mix. Structural cracks are more of a problem as some of them undergo significant movements which makes repair method selection difficult. Reference 27 states that the amount of corrosion required to cause cracking is quite small. A pit depth of 0.03 mm was found to be sufficient to crack a concrete cover of 22 mm. Cracks oriented perpendicular to the reinforcing steel are known to accelerate the corrosion of the intercepted bars by supplying easy access for moisture, oxygen, and chloride ions to penetrate to the level of the steel. Cracks that are oriented along the reinforcing steel are a more serious threat and cause much greater amounts of corrosion as the length of the bar equal to the length of the crack will corrode and the resistance of the concrete to spalling is reduced.

Crack widths less than 0.3 mm have little effect on the corrosion of the steel. After several years, even wider cracks have little influence on the extent of corrosion. This impact decreases because once the steel begins to corrode, as long as moisture and oxygen are available, the process will continue throughout the deck whether or not cracks are located above the reinforcing steel because a "macrocell" has already been developed.

4.3.2 Spalls and Delaminations

Spalling results from the corrosion of reinforcing steel due to the ingress of chloride ions or rather the use of de-icing salts on Ontario bridge decks. Spalling is the most severe deterioration caused by chloride ion attack, and it may involve significant amounts and thicknesses of concrete.

The spalling process begins with the development of delaminated surfaces. First, small cracks develop in the concrete surface providing the chlorides, moisture and oxygen access to the interior of the concrete deck. Once the chloride threshold level for steel corrosion is reached and in the presence of oxygen and moisture, corrosion of the reinforcing steel begins. Horizontal cracks develop in the concrete above the corroding steel bars due to the build up of iron oxides on the steel surfaces. Reference 27 reported that these oxides can take up as much as 2.2 to 13 times the volume of the original reinforcing steel. These horizontal cracks create fracture planes, commonly referred to as "delaminations". When deck surfaces are surveyed, delaminations are detected by dragging a specific size chain across the surface. Delaminated areas are detected when a hollow sounding area of concrete is found. Spalls form when the concrete in these delaminated areas pops off the surface. The spall can be caused by either the repetitive motion of vehicles driving over the delaminated area or from the action of water going through freeze-thaw cycles under the fracture plane. The ice takes up a larger volume than the water in the cracked plane creating pressure. When the pressure is large enough, the concrete above the fracture plane pops off.

4.4 Measurement of Corrosion of Reinforcing Steel

The Ontario Ministry of Transportation relies on a method of corrosion measurement that utilizes an external half-cell to assess the point at which the rate of oxidation of the steel exactly equals the rate of the reduction at the cathode. This method of measuring corrosion activity was first reported in 1973 but was not implemented by the Ministry until 1979 (Reference 24).

When the oxide film protecting the reinforcing steel is destroyed, the electrical potential of the steel is different from the situation where the oxide layer is intact. This occurrence makes it possible to use electrical measurements on the surface of the concrete to measure the potential risk of corrosion of the steel in various locations throughout the surface. This test is usually conducted at points on a closely spaced grid (see Structure Rehabilitation Manual, Reference 8, for specific grid distances). If the concrete surface is covered with asphalt, holes are drilled through the asphalt layer to expose the concrete surface in order for measurements to be taken (the holes are filled with soapy water which acts as the electrolyte). In order to take these measurements, electrical connections have to be made with the reinforcement and the concrete surrounding it. The connection is achieved by breaking out the concrete cover at a reinforcing bar location and connecting a lead wire to it. The lead wire is connected to the reinforcing steel by screwing a self-tapping screw into the top of the bar or by soldering the wire to the reinforcement. The connection with the concrete is achieved through the use of an electrolyte which wets both the concrete and the conductor which is connected to another wire. The electrolyte most commonly used is potable water mixed with dish washing

detergent. The probe is held on the concrete surface at the previously laid out grid intersection points. This probe is referred to as a half-cell or reference cell.

The other half of the cell is the reinforcement and the concrete. In all Ministry inspections the reference cell is a copper rod immersed in a saturated solution of copper sulphate. When in contact with the probe, these two cells form a complete electrical cell that represents a constant electrical potential. The electrical potential of the reference cell is compared to that of the steel embedded in the concrete. They are connected through a high-impedance millivoltmeter. The readings from the voltmeter are a measurement of the total potential difference between the reinforcement relative to the pore fluid and the potential of the probe.

The measurements presented in References 1 and 4 are accepted by the Ministry and are interpreted as follows:

- Potentials more negative than -0.35 V, (V = volts) indicate high probability of active corrosion of reinforcement
- Potentials in the range of -0.20 V to -0.35 V, indicate an uncertainty as to whether or not corrosion activity is taking place
- Potentials more positive than -0.20 V, indicate a high probability that no corrosion activity is taking place.

The corrosion potentials are plotted on the points of measure and contours are drawn at the limits specified above i.e. -0.20 V, -0.35 V, and -0.45 V. The deck area can then be measured within each of the contours to estimate a percentage of the deck area undergoing active corrosion. These potential measurements are not indicators of the rate of corrosion or of corrosion activity (related to the current flow) but rather measure the

probability that corrosion of the reinforcement is taking place at the time that the measurements are taken.

It should be noted here that since the steel in a bridge deck is easily oxidized and is considered to be an active metal and the copper in the reference cell is considered a more noble metal, the corrosion potential of the reinforcing steel is more negative than the reference cell. Therefore, the readings from the voltmeter are recorded as being negative.

CHAPTER 5

DATABASE DEVELOPMENT

Using DBASE III software, (DBASE is a proprietary system by Ashton-Tate Corporatoin) the Bridge Management Section of the Ontario Ministry of Transportation developed a 32 field database file to record incoming information from the deck condition surveys. This database was developed in summer 1990 to make record maintenance easier and information more readily available to those involved in the rehabilitation design phase.

In Webster's New World Dictionary, a database is defined, as "a large collection of data in a computer, organized so that it can be expanded, updated, and retrieved rapidly for various uses" (Reference 18). In DBASE, a field is a column where elements are defined in a consistent manner. Fields can be entered either in numeric, character, true/false question, or in a memo field form. Memo fields allow the storage of as many lines of text as is necessary to describe an element of the file. The database presented in this thesis uses DBASE IV software and was derived from the Ministry's original 32 field DBASE III file. It should be noted here that no detailed deck condition survey information had been input into the DBASE III file as it was still in the developmental stage. Seventeen (17) fields from this original database were used and 19 new fields were

developed for the purpose of this study and the use of the Ministry. This new format will allow future studies to be conducted without a lengthy data collection/input phase. Field descriptions are outlined in Table 5.1 and a printout of the database file is located in Appendix C. The information input into the database was located within the detailed deck condition survey files which had to be taken out of storage and in some cases came from storage files in the Ministry's Materials Department.

An explanation of several of the fields is outlined to give the reader an understanding of the terms used by the Ministry and how the data input value was determined. In Field 6, the AADT recorded is the most recent measurement taken and is not necessarily the 1990 average. AADT represents the annual average daily traffic which is the twenty-four hour, two-way traffic count between January 1st to December 31st of the year it is recorded. This field is required to analyze any effects of traffic volumes on the deterioration of Ontario bridge decks. Field 8 records the type of superstructure built. Ten (10) types of structures were observed as follows:

<u>TYPE NUMBER</u>	<u>DESCRIPTION</u>
1	Rigid frame
2	Concrete slab on beam/girder (steel or concrete)
3	Post tension deck slab
4	Voided slab
5	Box beam/girder (steel or concrete)
6	T-Beam
7	Truss
8	Culvert
9	Arch (steel or concrete)
10	Concrete/timber deck

Table 5.1
DESCRIPTION OF DATABASE FILE

FIELD No.	FIELD NAME	FIELD DESCRIPTION
1	SITE	Structure site number
2	NAME	Structure name/bridge #
3	REG	Region
4	DIST	District
5	HWY	Road that bridge carries
6	AADT	Average Annual Daily Traffic
7	YR_CONS	Year structure was built
8	TYPE	Number assigned to a specific type of structure
9	MTYPE	Description of type of structure
10	NO_SPAN	Number of spans
11	DECK_AREA	Deck area
12	SURFACE	Type of surface; asphalt or concrete
13	WPM	Structure waterproofed or not
14	N_C_SURV	Total number of condition surveys for site structure
15	YEAR_F_C_S	Year first condition survey conducted
16	YEAR_S_C_S	Year second condition survey conducted
17	CONC_COVER	Average cover to reinforcing steel
18	COMP_STR	Average compressive strength
19	AIR_CONT	Air entrainment, consider air content, specific surface and spacing factor
20	APOTEN1	Percentage of deck area with half-cells more negative than -0.35 V cse, first survey

(Table 5.1 continued)

FIELD No.	FIELD NAME	FIELD DESCRIPTION
21	APOTEN2	Percentage of deck area with half-cells between -0.2 and -0.35 V cse, first survey
22	ADEL_AREA	Area of delaminations, spalls and patches, first survey
23	ACHLORIDE	If chlorides have penetrated to level of steel, the input is, True
24	DEPTHCHLA	Average depth of chloride penetration, first survey
25	BPOTEN1	Percentage of deck area with half-cells more negative than -0.35 V cse, second survey
26	BPOTEN2	Percentage of deck area with half-cells between -0.2 and -0.35 V cse, second survey
27	BDEL_AREA	Area of delaminations, spalls and patches, second survey
28	BCHLORIDE	If chlorides have penetrated to level of steel, the input is true
29	DEPTHCHLB	Average depth of chloride penetration, second survey
30	RPOTEN1	Percentage of deck area with half-cells more negative than -0.35 V cse, measured during rehab. const.
31	RPOTEN2	Percentage of deck area with half-cells between -0.2 and -0.35 V cse, measured during rehab. const.
32	REH_DEL	Area of delaminations, spalls and patches, measured during rehab. const.
33	REHAB_YR	Year deck was rehabilitated
34	METHOD_REH	Short form types of rehabilitation
35	REMARKS	Details from condition surveys, cover, air content, see remarks memo outline sheet
36	DART	Information from DART report

Field 8 allows the results to be sorted and analyzed by structure type. Field 13 indicates whether the bridge deck had a waterproofing membrane at the time of the condition survey. The date that the waterproofing membrane was applied (during original construction or during a subsequent repaving project) was not recorded as it was not available. Maintenance of the membrane was also not available. The type of waterproofing observed at the time of the survey was recorded in Field 35, Remarks.

Field 14 represents the total number of detailed condition surveys that have been conducted on the specific structure. This thesis only utilizes those structures with an input value of "2" or greater in Field 14. It should be noted here that a "2" in this field does not necessarily indicate that more than one condition survey was required before rehabilitation took place. A "2" is also placed in this field for structures which had an initial detailed deck condition survey and a set of half-cell measurements taken during the rehabilitative construction contract. This practice is relatively new and was initially used by the Ministry to evaluate the reliability of the half-cell surveys (Reference 17). Field 14 was created such that these structures with two surveys could be sorted from the main file which contained more than 600 structures.

Field 17 was calculated by taking an average of all concrete cover to reinforcing steel measurements taken from the concrete cores and in the sawn asphalt sample areas. The maximum and minimum covers are recorded in Field 35. The compressive strength measurements were also recorded in Field 35, and the average measurement was recorded in Field 18. In Field 19, the measured air content is recorded to ascertain whether the concrete was properly air entrained at the time of placement. Air entrainment of concrete

was not practised widely in Ontario until after 1958. Consequently, the Ministry does not require air content tests on structures built before 1958.

Two separate fields were developed for monitoring the results of the half-cell tests. Fields were created for the percent of deck area with measurements more negative than -0.35 V cse (90% probability of active corrosion, POTEN1) and areas which lie between -0.20 and -0.35 V cse (uncertain corrosion zone, POTEN2). The first survey was labelled survey "A" and the second survey, "B". The information gathered during the rehabilitation contracts was labelled with an "R". The information stored in these fields is the basic measure of corrosion used in developing the deterioration curves presented in this thesis. These results are presented in six possible fields: APOTEN1 & 2, BPOTEN1 & 2, and RPOTEN1 & 2. The APOTEN field is completed for each structure. The BPOTEN is completed if a second condition survey was required before rehabilitation took place. The RPOTEN is completed if a second survey was not conducted but a survey was done during the rehabilitation contract. Until recently, the Ministry did not take half-cell readings when a structure was rehabilitated. Twenty (20) of the structures presented in this thesis had half-cell measurements which were taken during rehabilitative construction. In some cases, the measurements were only measured for half of the structure. The percentage was then extrapolated and applied to the entire deck area.

Fields 23 and 27 indicate the depth of the chloride penetration measured during the chloride content testing. These figures vary between surveys and do not always depict an increase in the penetration of chlorides in the second survey. This is the result of core samples being extracted in different locations on the deck surface. For a proper

comparison to be made between condition surveys regarding the penetration depth of chlorides, cores must be drilled adjacent to one another. Cores should also be retrieved from areas which show little deterioration with low half-cell measurements as well as in areas of deterioration with high half-cell measurements.

Fields 28, 29 and 33 are memo type fields where paragraphs of information can be stored. ADEL_AREA, BDEL_AREA and REH_DEL are memo fields which contain information for exposed concrete decks only. On an exposed concrete deck, a delamination survey (chain-drag) is carried out during the detailed condition survey. This survey reveals areas where the concrete is thought to be debonded from the reinforcing steel. This creates an area of deterioration referred to as a "delamination". Areas of delamination usually correspond to areas with high negative half-cell measurements where the steel is actively corroding. Of the exposed concrete decks used in this study, 73% include these results. If results were not made available or were not applicable, a N/A was input into the database file. This component of the survey can not be conducted on asphalt covered decks. However, in 1986, the first DART surveys were conducted which measures delaminated and debonded areas for asphalt covered decks (see explanation of Field 36). Approximately 10 DART surveys were conducted each year up to 1989 when approximately 100 surveys were conducted.

The method of rehabilitation, once construction has been completed, was also input into the database. This information will be useful for future studies. Acronyms were used to depict the following types of rehabilitation:

<u>ACRONYM</u>	<u>DESCRIPTION</u>
P.W.P.	Patch, waterproof and paving
O/LAY(N)	Normal slump concrete overlay
O/LAY(L)	Latex modified concrete overlay
CP	Cathodic protection
RD	Replace deck.

The final two fields are both memo fields with paragraphs of information. Field 35 gives a summary of the key findings of the detailed bridge deck condition survey. The results from concrete tests are noted as well as the condition of the asphalt and the waterproofing membrane (see Appendix B). Field 36 is a summary of the results of the DART survey. Debonded and delaminated areas, areas of scaling, average concrete cover, and average depth of asphalt are all recorded.

5.1 Data Collection

The data collected for this study is a portion of the information gathered in the detailed deck condition surveys conducted by the Ministry between 1978-90. As previously discussed, this injects a bias into the information gathered. In order for a detailed deck condition survey to be conducted on a structure, that structure must already show advanced signs of deterioration. The condition survey is usually conducted two years prior to any rehabilitation contract. Therefore, structures with little visual deterioration are generally not a part of the five year rehabilitation program and are not

included in the data presented. However, it must also be remembered that some of the rehabilitation contracts were scheduled due to the presence of paving contracts or realignments of the roadway crossing over the structure; therefore, a few structures without advanced signs of deterioration are also included in this study.

The second criteria used in the data collection process involved segregating the structures which had more than one set of results from the detailed deck condition surveys. This limited the number of files to be reviewed. This introduced another bias into the data collection process. The intent of the five year program set out by the Ministry is for a detailed condition survey to be conducted only on structures scheduled to be rehabilitated within two years. Because of lack of funds and at times the large number of structures requiring repair, a lapse of two years passes with some of the rehabilitations not being completed. In this case, a second detailed condition survey must be conducted, if four years has passed since the first survey to identify further deterioration and verify the type of rehabilitation proposed for the structure. The structures which are rehabilitated within the two year time limit are frequently those which require immediate attention. Therefore, only a few structures with extreme deteriorated conditions requiring immediate repair are represented in the data collected.

The data gathering/input time was also limited. Data was collected over a four month period, when the author worked on contract for the Ontario Ministry of Transportation. The first month was spent revising the database which the Ministry had developed, setting standards for input of memo fields, and sorting through information. The author also made contact with the Ministry's five Regional Structural Heads in an

attempt to generate a preliminary list of structures which had more than one set of detailed conditioned survey results available for input into the database. Approximately 175 structures had more than one set of condition survey results. Of these, 44 were found not to be useful for the following reasons:

- first condition survey completed before 1981 and could not be located
- second condition survey could not be located
- second condition survey only included measurements of expansion joints and a few concrete core samples, no half-cell measurements
- structure had concrete slabs on timber decking. Found that results were obscured by either the thin slab, presence of only one layer of reinforcing steel or by the effect of the creosote penetrating the underside of the concrete slab.

The earliest year where data was available in the form of a detailed deck condition survey was 1978. The first few years (1978 to 1981) of this data contained some dubious results. The problem lies in the accuracy of the corrosion potential test. In some cases it is thought that this test was not conducted accurately. In the field it is difficult to decipher whether the holes drilled for the half-cell tests have penetrated the pavement to the concrete deck surface. If the holes have not penetrated the asphalt, or the waterproofing layer, inaccurate measurements will result. Usually the drill operator looks for a white powder to appear at the point where the drill bit is lodged into the asphalt. This powder usually indicates that the concrete surface has been penetrated. The drill operator also looks for a rubbery ring to come out of the hole along the drill bit. This rubbery ring is the waterproofing membrane. Better controls are presently in place as all hole depths are measured and compared to the thickness of the asphalt layers recorded

from both nearby concrete cores and sawn asphalt samples. This study directly relies on the experience of the personnel in charge of conducting the half-cell test. The regression analysis results for the asphalt covered and asphalt with waterproofing covered decks should take into account the number of surveys conducted in the initial years when the quality control for the half-cell testing was not as good.

CHAPTER 6

DEVELOPMENT OF DETERIORATION CURVES

This chapter outlines the analyses performed on the database. As discussed in Section 6.4, preliminary studies, were conducted to assess the effects of several influences before developing the final deterioration curves. Three final sets of deterioration curves were developed for each type of deck protection (exposed concrete decks, asphalt covered decks and asphalt with waterproofing decks) which are as follows:

- 1/ Deterioration versus Age
- 2/ Deterioration and Concrete Cover Contours
- 3/ Rate of Deterioration versus Age.

The development of these three sets of curves is discussed in Section 6.5 of this chapter.

The deterioration of bridge decks in Ontario is a function of age, surface protection, concrete cover to the reinforcing steel, traffic volume, and the heavy use of de-icing salts to maintain bare pavement throughout winter months. Some of these parameters of deterioration are somewhat dependent on each other. For instance, important motorways have higher traffic volumes, which can mean more frequent and heavier applications of de-icing salts during the winter months. Quality of construction and design will depend on when the bridge was built. Over time, the quality of concrete

and of construction practices tends to improve as better products, admixtures, and specifications become available.

The measurement of the corrosion potential of reinforcing steel, through half-cell testing, is an integral component in determining the level of deterioration of bridge decks in Ontario. The type of rehabilitation undertaken by the Ontario Ministry of Transportation depends on the percentage of the deck surface area undergoing active corrosion, together with measurements of concrete cover and surface deterioration. Specific guidelines for choosing the type of rehabilitation to be implemented are outlined in Reference 8, Tables 3.1, 3.2, 3.3, 3.4 (see Appendix B, Figures B-1 to B-5). The measure of deterioration used by the Ministry is the percentage of the deck area that has potential measurements more negative than -0.35 V, this indicates the deck is undergoing active reinforcement corrosion. Corrosion potential measurements and average concrete covers were essential pieces of information for the development of deterioration curves in this thesis.

6.1 Method of Analyses

This study used a piece-wise method of linear regression analysis to give more reliable results as opposed to doing a regression analysis on the whole population. Several methods were attempted before this method was found to be the most useful. A regression analysis finds a model in which the dependent variable (y) is approximated by a linear combination of the independent variables (x_1, x_2, \dots, x_k), with a constant term, C in the form of $y = C + A_1x_1 + A_2x_2 + \dots + A_kx_k$. The regression analysis finds the values of

the coefficients of the "x" variables, A_1, A_2, \dots, A_k , and the constant C , such that for each value of "y", the values of $A_1x_1 + \dots + A_kx_k + C$ are as close to the values of "y" as possible in a least square sense. The correlation coefficient, R^2 , measures the validity of the model which indicates how well the least-squares regression line fits the data. R^2 is equal to the ratio of the sum of squares due to the regression to the sum of squares about the mean. The sum of squares about the mean shows that the variation in the "y's" about their mean can be attributed to the regression line and to the fact that the actual observations do not all lie on the regression line. A value of 1 or -1 is optimal as it indicates that the total variation is all explained by the regression line and that perfect linear correlation of the data exists. A value of 0 indicates that there are large variances of the data points from the regression line and the total variation is all unexplained by linear analysis. A standard error is calculated for the estimate of the "y" value and of the coefficients calculated for each independent variable. The least square regression curve produces the smallest standard error of the estimate. The standard error of the "y" values represents the deviation of the observed "y" values from the values of the linear combinations, $A_1x_1 + \dots + A_kx_k + C$. The standard error of the coefficients of the independent variables gives an error estimate of the coefficients calculated in the regression analysis. The coefficients should be interpreted as the given "X" coefficient value plus or minus the corresponding standard error of the coefficient. When one standard error is applied, the resulting range of the y-value will contain 68% of the data points. When two or three standard errors are applied, 95% and 99.7% of the data points will be within the estimated range of the y-value.

6.2 Age

The ages of the structures, at the time of their respective detailed condition surveys, used in this study range from 8 to 72 years. It has been suggested in previous studies that different construction practices and changes in the quality of concrete produced can sometimes be discerned through data gathered during the detailed deck condition surveys. These changes in construction practices include different types of surface protection applied to the concrete deck surface as discussed in Section 6.3. In 1977/1978 the Ministry adopted a multiple approach to protect the embedded reinforcing steel from corroding. Concrete cover to the reinforcing steel was increased, the use of epoxy coated reinforcing steel was implemented and the use of waterproofing membranes under the asphalt wearing course was continued.

In the development the first two sets of curves, Deterioration versus Age and Deterioration and Concrete Cover Contours, the results from both sets of detailed condition surveys were combined, regardless of structure. In developing the third set of curves, Rate of Deterioration versus Age, averages of all the deterioration measurements for specific age intervals were used regardless of structure. Therefore, different construction practices are not a determining factor in the prediction of deterioration using these three sets of curves.

6.3 Deck Surface Protection Groups

Three deck surfaces are prevalent throughout the province of Ontario; namely, exposed concrete decks, asphalt covered decks, and decks which have waterproofing

membranes between the asphalt wearing course and the concrete deck. Before 1960, decks were either left as exposed concrete decks i.e. concrete box girders where the top surface of the box was used as the riding surface, or the decks were covered with a nominal layer of asphalt. In 1963 the first unprotected exposed concrete deck, that was not an integral part of the superstructure, was constructed. This came about because of difficulties encountered when inspecting the top of the concrete deck surface for the asphalt covered decks being constructed. The exposed concrete deck surface became the norm by 1965 and continued to be constructed until 1972. During this period the highway network in Ontario expanded rapidly and subsequently 25% of Ontario's provincially owned bridges were constructed with exposed concrete deck surfaces. In the early 1970s, increased deterioration due to chloride penetration of de-icing salts, corrosion of the embedded reinforcing steel, was observed on exposed concrete deck surfaces. This led the Ministry to the decision to apply waterproofing membranes and an asphalt wearing course to all newly built bridge decks. It should be noted here some decks still have exposed concrete surfaces. Most of these surfaces are actually the surfaces of concrete overlays which were placed on top of the original deck surface. The chronological history of the various types of waterproofing membranes used is as follows:

- deck sealers; no longer used
- mastic membranes; no longer used
- asphaltic membranes; no longer used
- hot applied membranes covered with a layer of protection board (to prevent the penetration of aggregates into the membrane); presently specified.

The structures included in the database were separated into three deck surface protection groups: exposed concrete (no protection), asphalt covered, and asphalt covered with waterproofing.

6.4 Preliminary Studies

Three preliminary studies were conducted in order to assess the influences of traffic volumes, use of de-icing chemicals, and air entrainment on the levels of deterioration (percentage of deck area undergoing active corrosion) measured. These studies individually have merit in supporting specific practises of the Ministry. The low percentages of the structures within each protection group with valid information for these studies indicates that these factors can not be used as parameters in the development of the deterioration curves.

6.4.1 Traffic Volume

Previous researchers have surmised that deterioration is a function of traffic volume (References 7, 12, 16, 20, 21, 23 and 27). It is thought that higher volume motorways and emergency routes within communities i.e. to hospitals, demand a higher level of daily service than others. Heavier travelled roads and those on emergency routes are assumed to be given first priority to cleaning during winter storms and are usually the most frequently salted. By implication, higher concentrations of de-icing chlorides are available to increase the rate of corrosion of the embedded reinforcing steel as described in Chapter 4. To verify these assumptions, a separate analysis was conducted for the

exposed concrete deck group which correlated traffic volume, in the form of AADTs, age, and corrosion potential measurements. Twenty five structures were included in this group; but 7 (28%) of these did not have AADTs available for the analysis. A multiple linear regression analysis was conducted with AADT and age representing the independent variables and corrosion potential as the dependent variable. The AADTs in the database file represent the most recent value recorded. For this reason the corrosion potential measurements used in the regression analysis were only taken from the second set of detailed condition survey data. The correlation coefficient (R^2) was 0.14 and the following equation was developed:

$$Y = 8.31 + 2.5 \times 10^{-1}(\text{AGE}) + 5.7 \times 10^{-5}(\text{AADT}) \quad (6.1)$$

where "y" represents the estimated percentage of deck area that is actively corroding. The AADT coefficient is so small that the AADT term is an order of magnitude smaller than the AGE term. It is therefore concluded that AADT or traffic volume has little effect on the deterioration of the structures in this study. A review of the data collected in the remaining deck protection groups led to the same conclusion. Appendix C contains the three plots of AADT versus corrosion potential for all three of the deck protection groups. These plots indicate that as AADT increases the level of deterioration generally decreases. It is believed that this conclusion is due to the fact that the AADT's recorded in the detailed deck condition surveys are the values which were last recorded. In many cases these AADT's were taken between two and five years earlier than the detailed condition surveys. This makes the AADT study irrelevant in the development of the deterioration curves.

6.4.2 Use of De-icing Chemicals

The use of de-icing chemicals on Ontario highways and roadways during the winter months is considered necessary to maintain safe conditions for the transport of goods and foremost, the public. Sodium chloride and calcium chloride are the most commonly used de-icing chemicals. The latter is the most effective at lower temperatures but is more expensive than sodium chloride. Sodium chloride is more widely used as a de-icer in Ontario. Studies conducted by the Ministry indicate that salt use in Ontario has been increasing on average, since 1974 (References 14 and 15). There are several explanations for this increase: the number of days where the high temperature is conducive to salt use has increased significantly over the past few years, the number of storms has increased but have been of lesser severity, and a higher level of service is required on lower volume roads. Another important reason for an increase in salt usage is that maintenance line supervisors may be prosecuted and charged as being "negligent" in their duties if they do not follow the "bare pavement" policy. Thus, patrol supervisors tend to err on the side of caution and oversalt the roadways under their supervision.

The increase in usage appears to be consistent throughout the province (see Appendix D for salt usage comparisons for the province and its Districts; these were prepared by the Ministry). Districts 1,3,6,9, and 16 to 20 show a more rapid increase in salt use than the remaining 13 Districts. In 1989/90, the most salt used per saltable two lane kilometre occurred in District 16 (59 tonnes), District 18 (53 tonnes) and District 5 (47 tonnes). The average amount of salt used throughout the province between the 1974 and 1981 winters was 412 tonnes and the average between the 1981 and 1989 winters was

557 tonnes. This represents a 35.2% increase in the average consumption of de-icer salts in Ontario over the past five years.

Where concrete cores were tested for chloride content, the concentration of chlorides was recorded as part of the detailed deck condition surveys. To make use of this information, if the concentration of chlorides was above the threshold value (0.02%) to initiate corrosion at the average depth of the concrete cover to the reinforcing steel, it was assumed the chlorides had penetrated to this level (these decks are referred to as "penetrated" for the remainder of this thesis). Separate comparisons were made for each surface protection group. These are tabulated in Table 6.1. As expected the average age for a given penetration increased with increased deck surface protection. However, the average percentage of deck area assumed to be undergoing active corrosion is proportionately higher for the asphalt covered decks than for the exposed concrete decks penetrated by chlorides. The average age of the decks which indicated that the chlorides did not penetrate to the level of the reinforcement was approximately the same as for those that indicated penetration had occurred. The average concrete cover to the reinforcing steel for all protection groups was 10 mm deeper for the decks that had not been penetrated by chlorides:

	<u>Penetrated decks</u>	<u>Unpenetrated decks</u>
Exposed concrete decks	55 mm	65 mm
Asphalt covered decks	49 mm	85 mm
Asphalt with waterproofing decks	54 mm	64 mm

Table 6.1

CHLORIDE PENETRATION SUMMARY

	EXPOSED CONCRETE	ASPHALT COVERED	ASPHALT WITH WATERPROOFING
% of structures with data available	46	71	74
% of structures where chlorides penetrated to the level of steel	61	54	58
avg. age (yrs.) of structures where chlorides penetrated to the level of the steel	16	28	30
avg. % deck area with corrosion potentials more negative than -0.35 V, on structures where chlorides penetrated to the level of the steel	10	25	15
earliest age (yrs.) that chloride penetration was noted	13	14	19
latest age (yrs.) that chloride penetration was noted	17	49	29
avg. age (yrs.) of structures where chlorides did not penetrate to the level of the steel	17	29	28
avg. % deck area with corrosion potentials more negative than -0.35 V, on structures where chlorides did not penetrate to the level of the steel	13	16	6

In the case of both the asphalt covered and asphalt with waterproofing decks, as expected, the percentage of deck area assumed to be undergoing active corrosion was less for the decks where chlorides did not penetrate to the level of the reinforcing steel. The percentage of the deck area undergoing active corrosion for these decks was approximately half the value of those decks that evidenced chloride penetration to the reinforcing steel. In the case of the exposed concrete decks, the percentage of deck area assumed to be undergoing active corrosion for the non-chloride penetrated decks is actually higher than for the decks with chloride penetration. The structures recorded as being the earliest and latest to indicate chloride penetration for each deck protection group, exposed concrete, asphalt and asphalt with waterproofing, were located in Districts 4,9,1 and 19,7, and 20 respectively. These results are not consistent with the list of Districts which showed more rapid increases in their use of de-icing chemicals. Perhaps these results indicate that the small difference in the amount of de-icing salts applied to the various highways under the Ministry's supervision does not significantly affect the rate of deterioration of the bridge decks. The data under consideration here did not include the individual amounts of de-icing salts applied to different stretches of the highways; therefore, separate correlations of deterioration rates to the quantity of de-icer salts applied to the decks could not be conducted.

The average age of the decks which were penetrated by chlorides increased, as expected, with increased deck protection. This indicates that the decks with more protection generally do not show signs of deterioration as early as the unprotected decks. The age differences between the earliest deck to be penetrated by chlorides compared to

the latest deck to be penetrated can be explained by reviewing the average covers of these particular decks. For the exposed concrete decks, the deck at 13 years of age with chloride penetration has an average concrete cover of only 33 mm, whereas the deck at 17 years of age, latest age of penetration, has an average cover of 58 mm. A similar pattern was observed for both the asphalt covered and asphalt with waterproofing decks.

6.4.3 Air Entrainment

Entraining concrete with air voids has proven useful in preventing the deterioration of concrete and has been used in Ontario since 1958. Thirty five of the 131 structures included in this study were found to be properly air entrained. The Ministry considers a concrete deck to be properly air entrained when the air content exceeds 3%, the spacing factor between air voids is less than 0.20 mm, and the specific surface exceeds $24 \text{ mm}^2/\text{mm}^3$ (Reference 3). The data collected suggests that proper air entrainment of concrete decks was not achieved consistently until 1964. Seventy-one percent of the decks surveyed that were constructed between 1958 and 1964 were not properly air entrained as compared to only 39% of the decks constructed after 1964 which were not properly air entrained. In the case of exposed concrete decks, 50% of the decks surveyed were properly air entrained. Only 14% of asphalt covered decks and 25% of asphalt with waterproofing covered decks were properly air entrained. Table 6.2 presents a summary of air entrainment and the tendencies towards deterioration.

When the percentages of the deck area undergoing active corrosion for the decks without air entrainment are linearly extrapolated to the average ages of those decks with

Table 6.2

AIR ENTRAINMENT SUMMARY

	EXPOSED CONCRETE	ASPHALT COVERED	ASPHALT WITH WATERPROOFING
% of structures with data available	50	14	25
avg. age (yrs.) of structures with proper air entrainment	15	19	17
avg. % deck area with corrosion potentials more negative than -0.35 V, with proper air entrainment	12	2	3
avg. age (yrs.) of structures without proper air entrainment	17	26	29
avg. % deck area with corrosion potentials more negative than -0.35 V, without proper air entrainment	17	17	9

air entrainment, the amount of deterioration can be compared. A 25% increase in deterioration is measured for the exposed concrete decks without air entrainment. A 520% increase in deterioration for the asphalt covered decks and 77% for the asphalt with waterproofing decks without air entrainment. The advantages gained by air entrainment are the least for the exposed concrete deck protection group. It should be noted that the average cover for this group of decks is 54 mm. Average concrete cover for asphalt covered and asphalt with waterproofing decks is 71 mm and 58 mm respectively.

The results from the asphalt with waterproofing group are suspect. The data was subdivided into two groups, those decks with over 40 years of service and those with less than 40 years of service. An average of only 1% of the deck area was undergoing active corrosion for those bridge decks over 40 years of age compared to an average of 11% for the younger decks. These results are contrary to what is expected as the decks with over 40 years of service were not air entrained at the time of construction. A possible explanation for this discrepancy is construction and design practises for the structures older than 40 years entailed the use of only one layer of reinforcing steel in the middle of the deck. This resulted in significant concrete covers to the reinforcing steel. Presently two mats of reinforcing steel are placed in slightly thicker decks. The concrete cover achieved during construction to the top mat of steel is less than that achieved to the one layer of steel in the older decks. As previously mentioned increasing the concrete cover greatly decreases the rate of chloride penetration to the level of the reinforcing steel. This indicates that the influence of air entrainment is not as important as the concrete cover to the reinforcing steel.

This preliminary study illustrates the importance of air entrainment in increasing the service life of concrete decks. However, there is not a significant number of data points available for analysis within each deck protection group to include air entrainment as a parameter in the development of the deterioration curves.

6.5 Deterioration Curves

Three sets of deterioration curves were developed for each type of deck protection (exposed concrete decks, asphalt covered decks, asphalt with waterproofing decks) as follows:

- 1/ Deterioration versus Age: Figures 6.1 (a) and (b), 6.2 (a) and (b), 6.3 (a) and (b).
- 2/ Deterioration and Concrete Cover Contours: Figures 6.4 (a) and (b), 6.5 (a) and (b), 6.6 (a) and (b).
- 3/ Rate of Deterioration versus Age: Figures 6.7 (a) and (b), 6.8 (a) and (b), 6.9 (a) and (b).

These sets of curves do not consider the influence of traffic volume, depth of chloride penetration (chloride ion content), or air entrainment as the preliminary studies indicated that these parameters either did not have measurable effects on the deterioration of the bridge decks included in this study or there were too few structures to make a proper comparison. The curves do consider the influences of deck surface protection and age. The latter two curves also consider the influence of concrete cover on the deterioration process. Each set of curves is separated into the three deck protection groups. The

Deterioration versus Age Curves were used as a starting point for analysis of the data collected. The resulting regression equations had relatively low correlation coefficients for all three types of protection groups and are not that useful.

A single variable piece-wise linear regression analysis was conducted in order to develop the Deterioration versus Age set of curves. A multiple regression analysis was conducted in the development of the contour line graphs. Age was found to be the most important parameter in the corrosion process of the embedded reinforcing steel. Note that age does not represent the age of the structures at the time this study was conducted (1991) but rather the age of each individual structure at the time of the detailed condition survey or rehabilitation construction. This principle is true for all three sets of curves where age appears as an axis of the graph. The Rate of Deterioration versus Age Curves did not involve a separate regression analysis but represent a numerical derivation of the data. These rate curves are the most useful for estimating future deterioration trends within the respective deck protection groups. The following sections outline the steps taken in the development of the three individual sets of curves.

6.5.1 Deterioration versus Age

In the development of this set of curves, the percentage of deck area which contained corrosion potential readings more negative than -0.35 V (actively corroding at time of measurement) was plotted against the age (at the time of the detailed condition survey) for each of the structures. The results of the first and second detailed condition surveys (or corrosion potential measurements taken during rehabilitation) were plotted

regardless of structure. This increased the number of data points for the analysis but did not allow a "rate of deterioration" for the individual bridge decks to be estimated as the points plotted were not identified by site number.

In figure (a) for each deck protection group, the data points which are circles were excluded from the piece-wise linear regression analysis. In figure (b) for each deck protection group, the mean age and one standard deviation (plus and minus), based on a normal distribution curve, are located. The limits of the one standard deviation represents the age range where 68% of the data points are distributed.

6.5.1.1 Exposed Concrete Decks: Figures 6.1 (a) and (b)

Twenty four structures with exposed concrete riding surfaces were available for analysis. For the curve developed in Figure 6.1 (a), the data points were plotted and a piece-wise linear regression analysis was conducted for various age groups. These age groups were selected by visually assessing the plotted data and conducting several regression analyses to find the best fit curve (highest correlation coefficient). Data points which skewed the results were excluded from the equation derivation. These data points were from sites which either had results that indicated very high corrosion at early ages or very low levels of deterioration at later ages. For example, site 07-098 had corrosion potentials more negative than -0.35 V over 90.3% of its deck area after only 13 years of service. This particular structure was not air entrained and had an average concrete cover of only 45 mm. Site 48C-102 had low levels of deterioration and only 4.1% of its deck area had corrosion potentials more negative than -0.35 V after 22 years of service. This

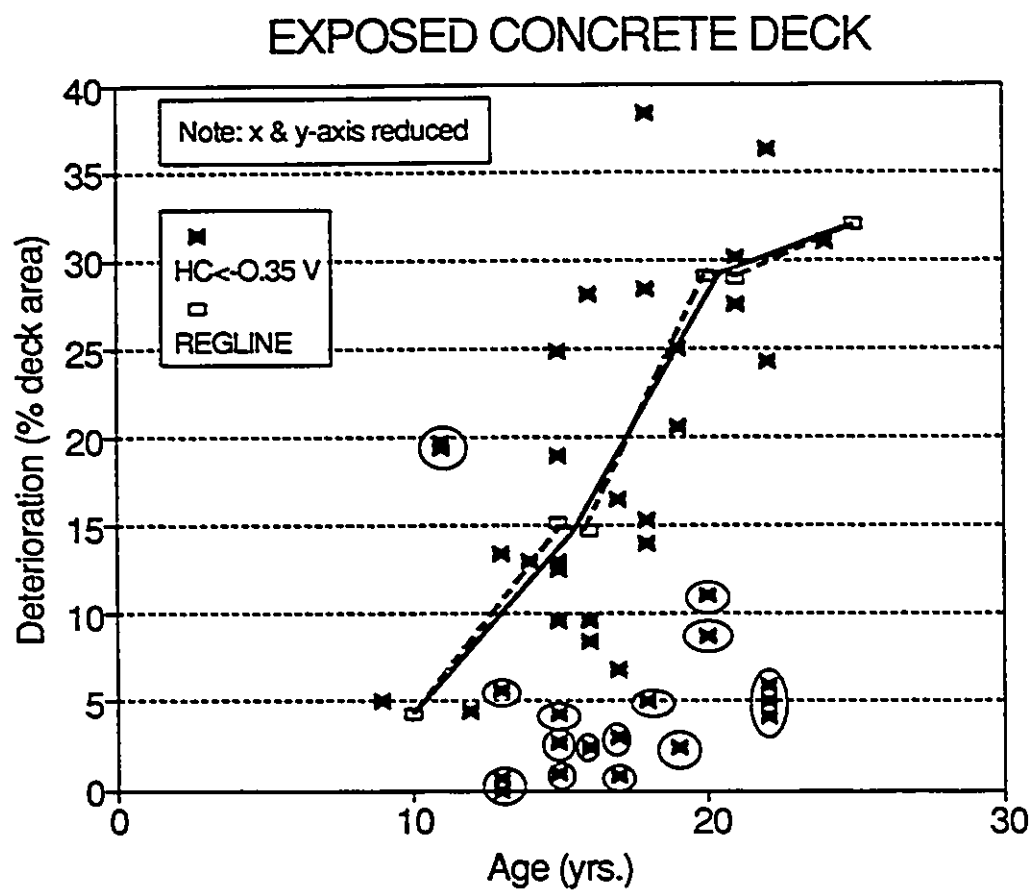


Figure 6.1 (a) Deterioration vs. Age

(circled data points excluded from regression analyses)

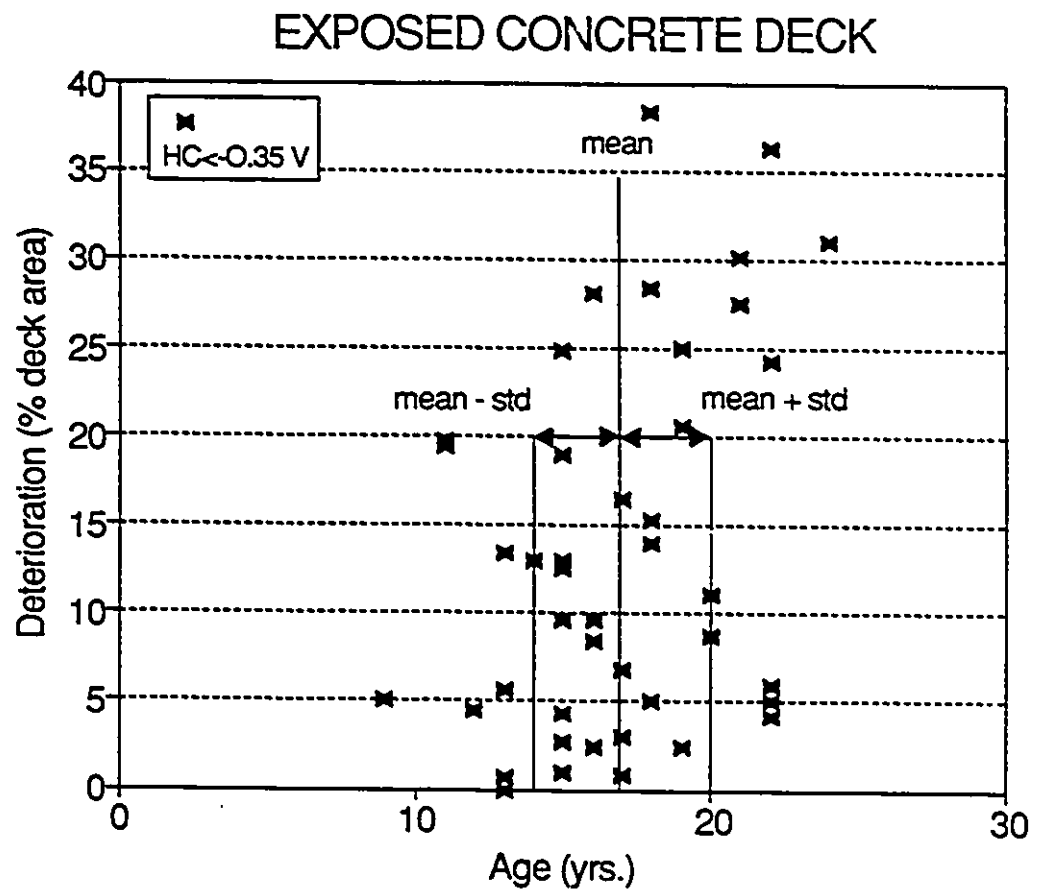


Figure 6.1 (b) Deterioration vs. Age

structure was also not air entrained but had an average concrete cover of 63 mm. It should be noted that this structure is a post-tensioned deck and only nominal reinforcing steel was used, which would explain the relatively low levels of deterioration observed.

The age group separations were chosen as follows: 9-15 years, 16-20 years, and greater than 21 years. In Figure 6.1 (a), the resulting regression equations are depicted by the dotted line. The solid line represents the final deterioration curve. The individual regression equations for the piece-wise regression analysis are listed in Table 6.3.

All the data points were used in calculating the mean age and respective standard deviation illustrated in Figure 6.1 (b).

6.5.1.2 Asphalt Covered Decks: Figure 6.2 (a) and (b)

Thirty six structures with an asphalt riding surface without a waterproofing membrane at the interface between the concrete and the asphalt were available for analysis. Site number 31-101 was excluded from the results as this structure had received a 160 mm concrete overlay as a rehabilitative measure. Rehabilitated decks are not a part of this study and warrant a separate deterioration study.

The age group separations chosen for the development of the curves illustrated in Figure 6.2 (a) were as follows: 17-25 years, 26-30 years, 31-40 years and greater than 41 years. The individual regression equations for the piece-wise regression analysis are listed in Table 6.3 and the subsequent deterioration curve for this deck surface group is illustrated in Figure 6.2 (a) as the dotted curve. The two solid curves represent the two deterioration curves which were ultimately derived from the regression analysis.

Table 6.3

DETERIORATION vs. AGE REGRESSION EQUATIONS

A/ EXPOSED CONCRETE DECKS

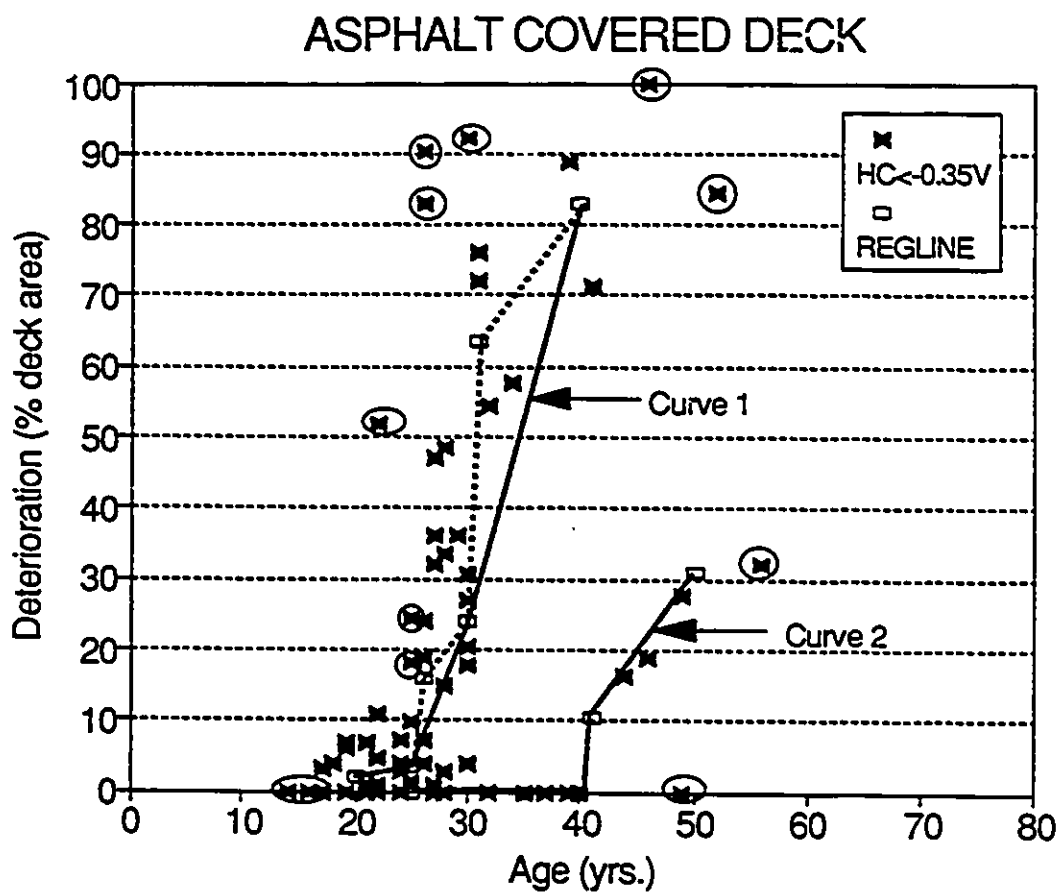
AGE	EQUATION	R ²	STD ERR AGE	STD ERR %	# DATA PTS.
9-15	% = -17.4 + 2.2(AGE)	0.43	0.87	5.1	10
16-20	% = -42.9 + 3.6(AGE)	0.17	2.7	9.5	11
>20	% = 14.1 + 0.7(AGE)	0.04	2.1	5.0	5

B/ ASPHALT COVERED DECKS

AGE	EQUATION	R ²	STD ERR AGE	STD ERR %	# DATA POINT S
17-25	% = -4.0 + 0.3(AGE)	0.11	0.19	3.2	26
26-30	% = -25.6 + 1.6(AGE)	0.02	2.5	16.2	21
31-40	% = -4.73 + 2.2(AGE)	0.28	2.1	13.9	5
>40	% = -83.9 + 2.3(AGE)	0.97	0.40	1.4	3

C/ ASPHALT WITH WATERPROOFING

AGE	EQUATION	R ²	STD ERR AGE	STD ERR %	# DATA POINTS
10-16	no equation available	N/A	N/A	N/A	-
17-24	% = 3.9 + 0.04(AGE)	0.004	0.40	5.7	33
25-29	% = -16.7 + 0.94(AGE)	0.016	1.5	10.3	27
30-39	% = -93.7 + 3.2(AGE)	0.37	0.89	11.0	24
>39	% = -27.9 + 0.81(AGE)	0.061	0.82	17.1	17



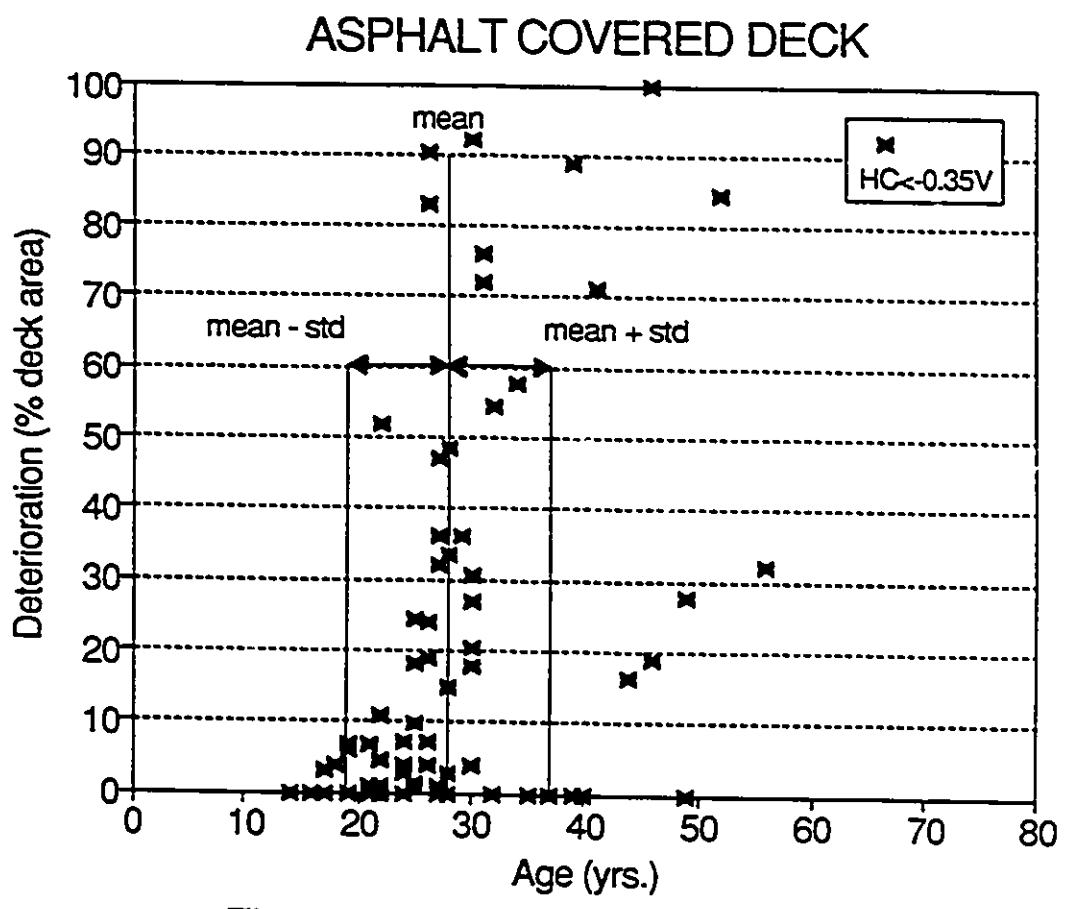


Figure 6.2 (b) Deterioration vs. Age

Curve 1 represents the more rapidly deteriorating decks younger than 40 years of age and curve 2 represents the slower deteriorating decks, including those exceeding 40 years. Concrete covers varied from a low of 38 mm to a high of 110 mm. Some of these structures were likely put on the Ministry's rehabilitation program because road work was being done in the area whereas only a few of the structures over 40 years of age were chosen because of their levels of deterioration.

All the data points, excluding site 31-101, were used in calculating the mean age and respective standard deviation illustrated in Figure 6.2 (b).

6.5.1.3 Asphalt with Waterproofing Covered Decks: Figure 6.3 (a) and (b)

Sixty nine structures with an asphalt riding surface and a waterproofing membrane between the concrete deck and asphalt wearing course are included in this deck protection group. No accurate record could be found as to when the waterproofing layers were applied to the various bridge decks. Therefore, these results tend to have large variations. As well, larger standard errors were calculated for both the independent and dependent variables in the piece-wise linear regression analysis. If available, the type of waterproofing found under the asphalt was recorded in Field 35 (REMARKS) of the database.

The age group separations for the development of the curves in Figure 6.3 (a) were more difficult to distinguish for this set of data because of the large number of "zero values". The data indicated that many of the structures did not contain actively corroding reinforcing steel for up to 30 years of age, and in one case, 70 years. Nineteen of the 69

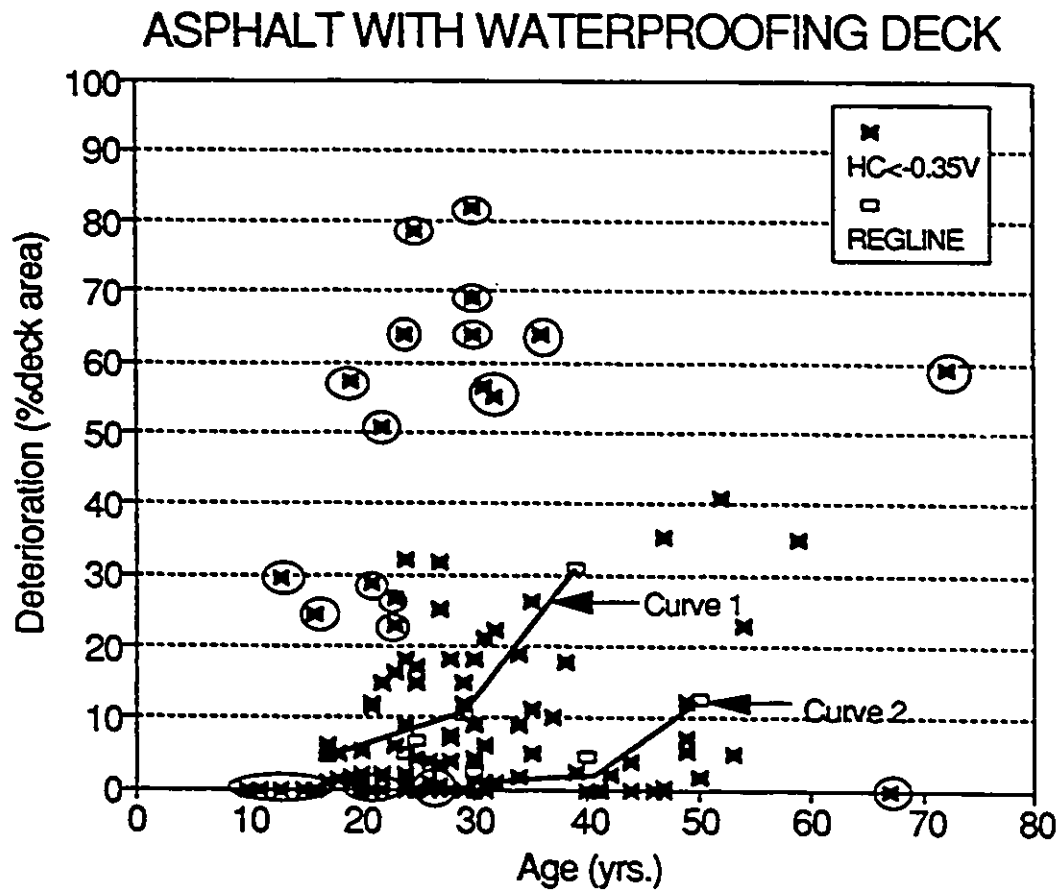


Figure 6.3 (a) Deterioration vs. Age

(circled data points excluded from regression analyses)

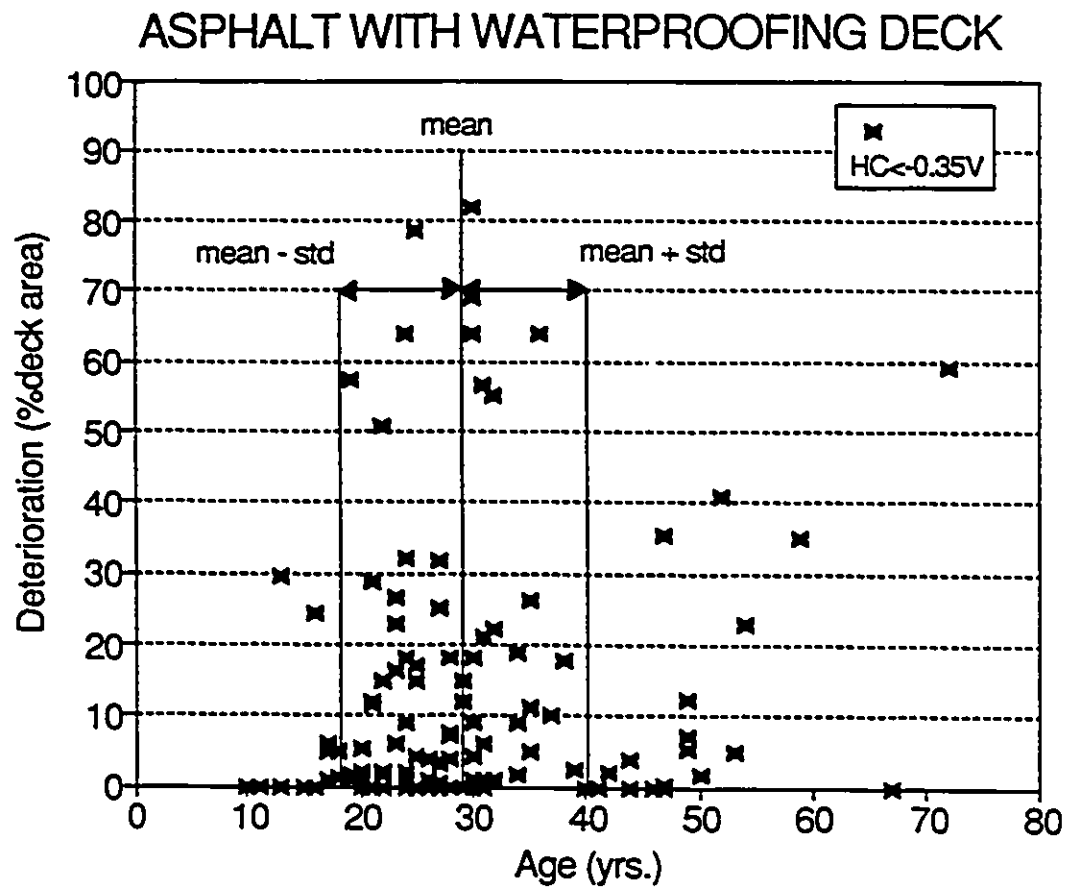


Figure 6.3 (b) Deterioration vs. Age

structures had zero values for the percentage of the deck area undergoing active corrosion of the reinforcing steel. Forty of the 69 structures had their first detailed condition surveys conducted in 1981 or earlier. Of these 40 bridge decks, 24 had active corrosion measurements over less than 1% of the deck area. These 24 bridge decks and other bridge decks with erratic data points were removed from the regression analysis. Such data points included bridge decks with very high corrosion potentials (above 50% of the deck area was actively corroding) at relatively young ages. Again, the data is very "age" sensitive. When the age groups are expanded or reduced by one year, the correlation factor, R^2 , decreases for the model. The individual regression equations for the piecewise regression analysis are listed in Table 6.3. Two deterioration curves were also developed for this deck protection group (see Figure 6.3 (a)). Curve 1 represents the more rapidly deteriorating decks younger than 40 years of age and curve 2 represents the slower deteriorating decks, including those exceeding 40 years. The concrete covers varied from a low of 30 mm to a high of 105 mm. As remarked in section 6.5.1.2, some of these structures were likely put on the Ministry's rehabilitation program because of roadwork being done in the vicinity of the bridge deck. Another explanation for the two distinct curves presented is that certain types of waterproofing membranes are more effective than others. Also, some of the structures with lower levels of deterioration could have been waterproofed earlier in their service life than others. These two factors were not readily extractable from the data collected or were simply not available.

6.5.2 Deterioration and Concrete Cover Contours: Figures 6.4 (a) and (b), 6.5 (a) and (b), 6.6 (a) and (b)

These graphs were developed such that the age of the structure and the concrete cover to the top mat of reinforcing steel and the type of deck protection could be considered joint factors in the determination of the level of corrosion of the reinforcing steel. Several steps were taken in the development of the regression equations to derive both sets of contour lines. First, the concrete cover was plotted against age for all data points collected. These points were plotted regardless of structure to allow for the assessment of the level of deterioration of various covers at different ages. Initial regressions were conducted using the percentage of the deck area undergoing active corrosion as the main data separator. The data was separated according to the amount of deck area undergoing active corrosion, i.e. less than 5%, between 5 and 10%, between 10 and 20%, and between 20 and 30%. These percentages correspond with the percentages outlined in part two of the Structure Rehabilitation Manual (Reference 8) for the various types of rehabilitations. Several other parameters such as the area of the deck surface that has delaminated and spalled, are taken into account in the flow charts developed by the Ministry. These parameters are not part of this study. The three types of rehabilitation methods presented in the flow charts are as follows:

P.W.P. - Patch, waterproof, and pave; 5 to 10% of the deck surface has corrosion potential measurements more negative than -0.35 V and areas of concrete cover to reinforcing steel of less than 20 mm extends over less than 10% of the deck surface area.

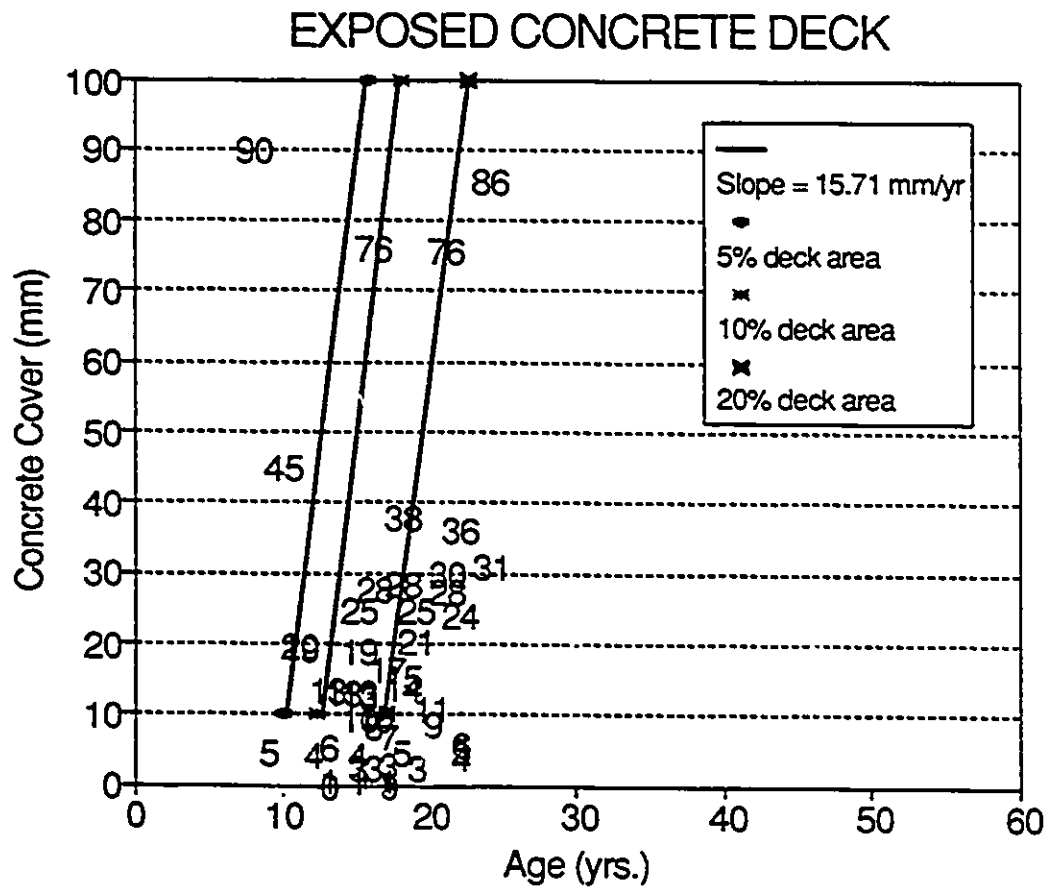


Figure 6.4 (a) Deterioration Contours

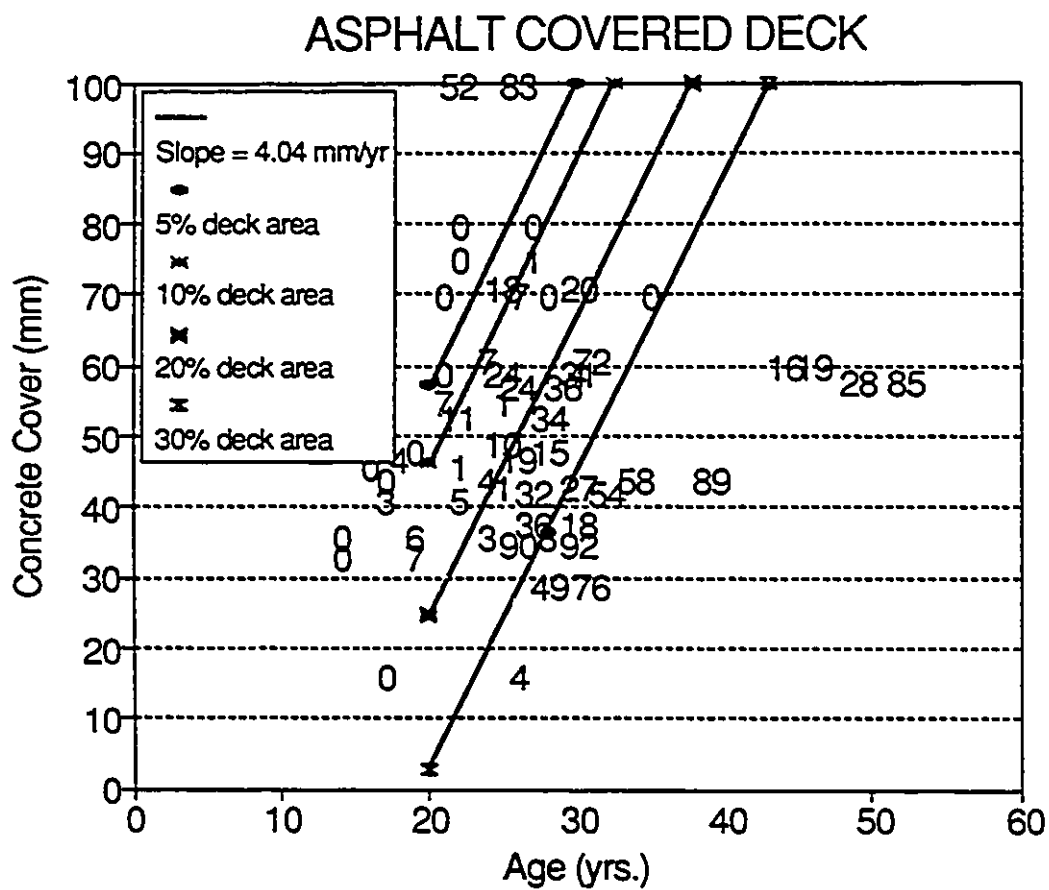


Figure 6.5 (a) Deterioration Contours

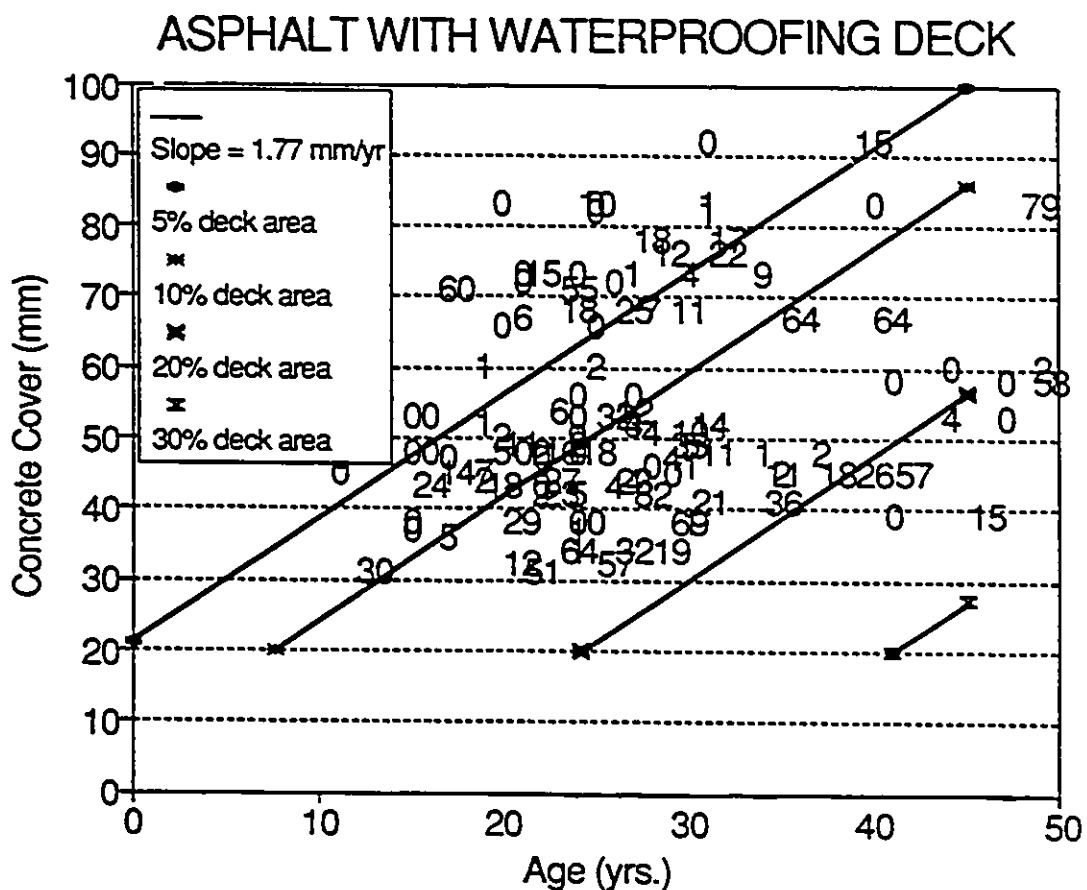


Figure 6.6 (a) Deterioration Contours

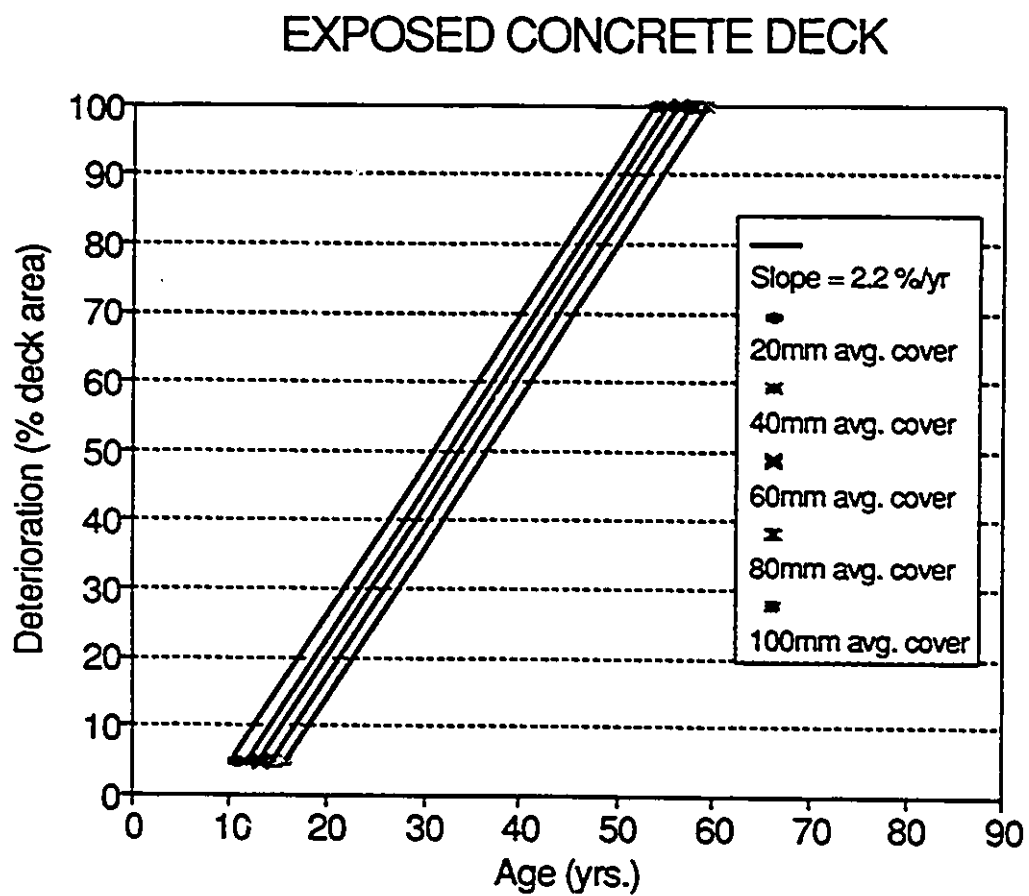


Figure 6.4 (b) Concrete Cover Contours

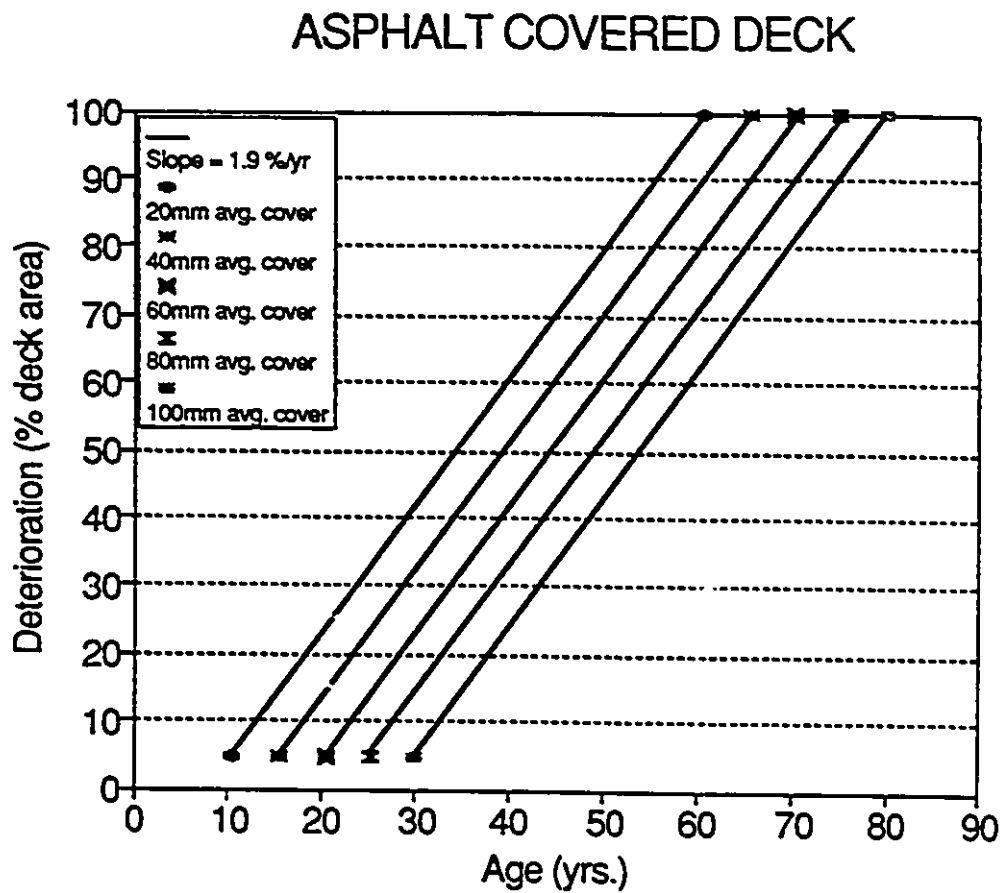


Figure 6.5 (b) Concrete Cover Contours

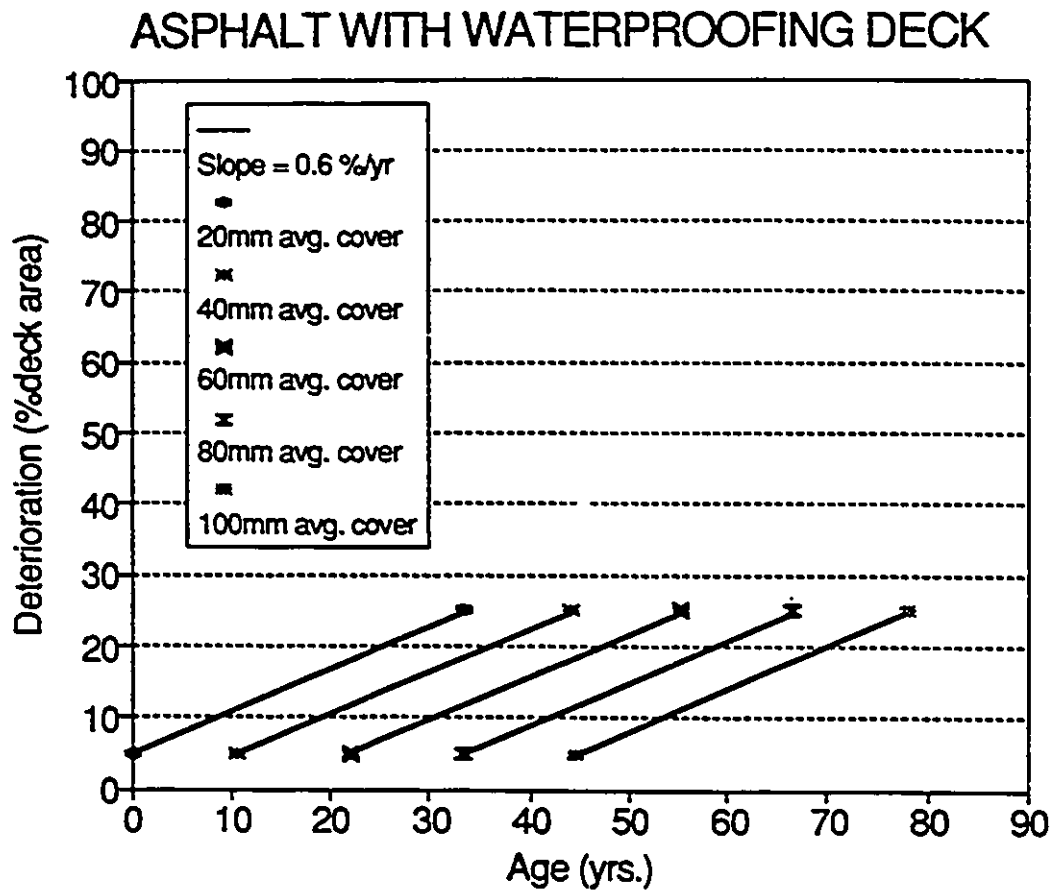


Figure 6.6 (b) Concrete Cover Contours

O/LAY - Latex modified or normal slump concrete overlay: more than 10% of deck surface has corrosion potential measurements more negative than -0.35 V or area of the deck with concrete cover to reinforcing steel; less than 20 mm extends over more than 10% of the deck surface area.

C.P. - Cathodic protection: more than 20% of deck surface has corrosion potential more negative than -0.35 V with the majority of the concrete in this area being sound.

Therefore, "deterioration contour lines" were developed at 5, 10, and 20% respectively. Data points were deleted in the original regressions in order to obtain the highest possible correlation coefficient for each of the "percentage" groups.

A multiple linear regression analysis of all the remaining data points was then conducted. One equation was developed for each of the three of deck protection groups. These equations are presented in Table 6.4. The correlation coefficients for this set of curves improved from the first set of curves but were still less than 0.5. The contour lines for 5, 10, 20, and in the asphalt covered and asphalt with waterproofing covered decks, 30%, were then plotted. For the concrete cover contours, the same regression equations were used but the graph was revised so that the y-axis represented the percentage of deck area undergoing active corrosion. The concrete cover contour lines were plotted illustrating the equations derived in Table 6.4 for various average concrete covers, 20 mm, 40 mm, 60 mm, 80 mm and 100 mm (see Figures 6.4(b), 6.5(b), and 6.6(b)).

Table 6.4

CONTOUR LINE REGRESSION EQUATIONS

EXPOSURE CLASS	EQUATION	R ²	STD ERR AGE	STD ERR COVER	STD ERR Y	# DATA PTS.
Exposed Concrete	% = -15.8+2.2(AGE) -0.14(COVER)	.40	0.51	0.11	8.2	33
Asphalt Covered	% = -5.9+1.9(AGE) -0.46(COVER)	.40	0.33	0.10	20.2	65
Asphalt with Waterproofing	% = 12.2+0.6(AGE) -0.34(COVER)	.14	0.17	0.10	15.9	102

6.5.3 Rate of Deterioration versus Age: Figures 6.7, 6.8 and 6.9

In developing the Rate of Deterioration versus Age Curves, the deterioration over time for a specific structure was assessed individually within each deck protection group. Regression analysis methods were not used for the development of this set of curves. A linear rate of deterioration was interpreted for each individual structure in intervals of five years. The value of the rate at the end of the five year divisions was assigned as the final rate for that division. The resulting rates are tabulated in Appendix E, Tables E-1, E-2, and E-3. These rates were calculated for the final year of the five year division and were multiplied by a factor of 100 in order to avoid decimal places in the Tables. If rates were not available for the final year of a five year division the last year rate available was used. The individual rates were then averaged within each deck protection group to attain an average rate of deterioration at the average age of each five year interval. The resulting Rate of Deterioration Curves are illustrated in Figures 6.7, 6.8, and 6.9. Only data from one structure was omitted from each of the exposed concrete and asphalt covered deck protection groups, and eight were omitted from the asphalt with waterproofing group. These structures were deleted because their rate of deterioration was much faster than the remaining structures in their respective protection groups. The deletion of these structures improved the shape of the Rate of Deterioration Curves.

The "rate of deterioration" has two stages. The initial rate of deterioration is defined in this study as the amount of deterioration measured at the time of the first condition survey as compared to no deterioration at the time of the initial construction. The second stage is the amount of deterioration which occurred between the two detailed

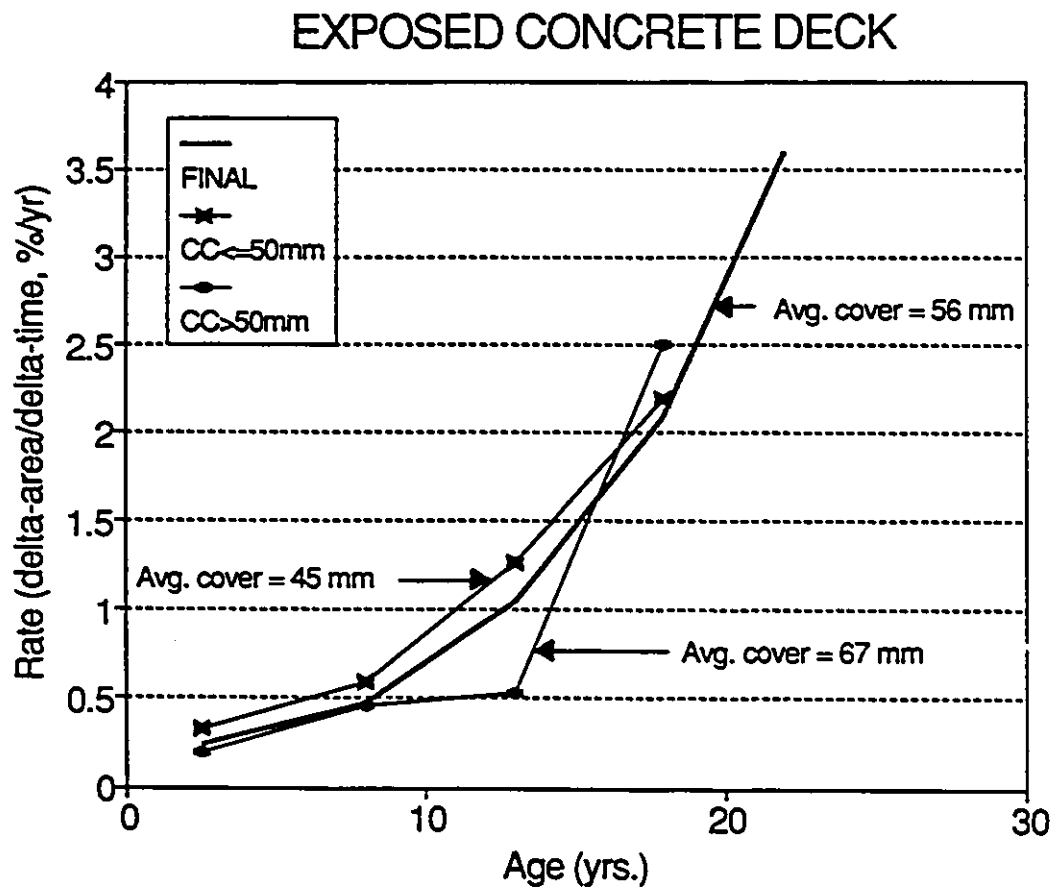


Figure 6.7 Rate of Deterioration vs. Age

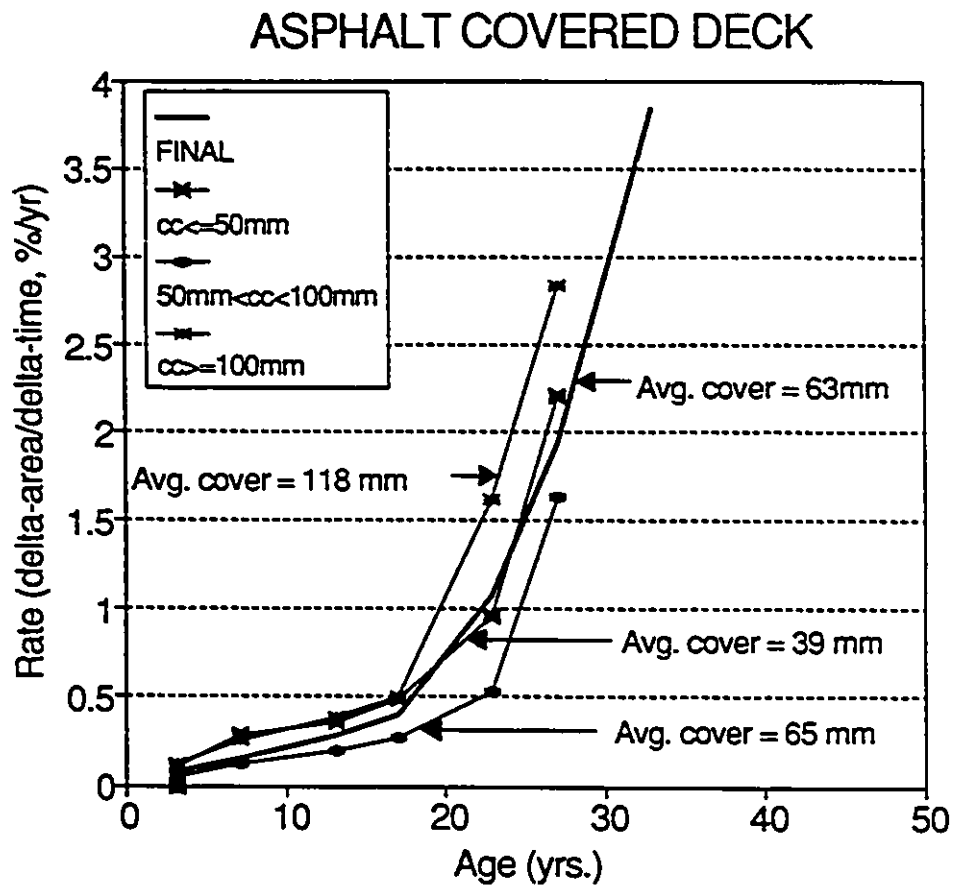


Figure 6.8 Rate of Deterioration vs. Age

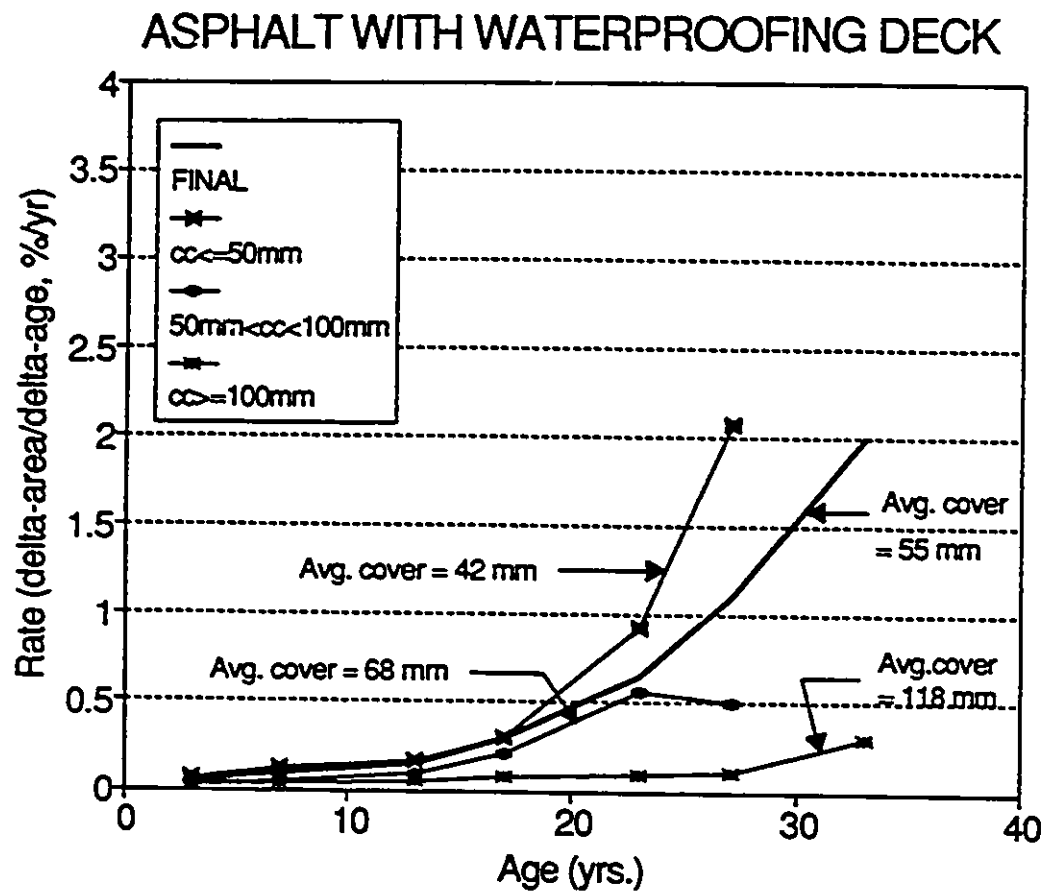


Figure 6.9 Rate of Deterioration vs. Age

deck condition surveys or between the first condition survey and the subsequent rehabilitation contract. The data was again grouped according to the type of deck surface protection. Three separate curves were developed. The population of the individual deck protection groups were analyzed as a group and then split further into different concrete cover groups; such as, average concrete cover being either less than or equal to 50 mm, between 50 mm and 100 mm (greater than 50 mm for the exposed concrete exposure category) or greater than or equal to 100 mm.

The individual rate curves were then plotted for each deck protection group. A final overall average curve was drawn through the plots of the individual curves. This curve is representative of the average rate of deterioration of the population of data utilized in this study. The rates calculated in Tables E-1, E-2 and E-3 after 27 years of age for both the asphalt covered and asphalt with waterproofing decks were not plotted as the number of data points with information in these age intervals was only 20 to 30% of the original number of data points available.

The rates were calculated as follows:

1/ RATE_i - is the value of the percent of the deck area with corrosion potential measurements more negative than -0.35 V in the first condition survey divided by the age of the structure at the time of the first condition survey (nomenclature from Table 5.1, APOTEN₁/[Y_{F_C_S} - YR_CONS]). It was assumed that this initial deterioration occurred at a constant linear rate from the day of construction. This initial rate, RATE_i, was then prorated in five year divisions with the year of construction as age zero up to the age of the first condition survey.

2/ RATE1 - is the difference in the percentage of the deck area with corrosion potential measurements more negative than -0.35 V between the first detailed condition survey and the second detailed condition survey divided by the number of years between the subsequent surveys (nomenclature from Table 5.1, $[BPOTEN1 - APOTEN1] / [Y_S_C_S - Y_F_C_S]$). This deterioration was also prorated linearly over the time between the two condition surveys. If the first condition survey was conducted within one of the five year divisions, the results from the RATE1 and the RATEi calculations were proportioned to calculate the rate for the final year of the five year division. In some instances, the RATE1 value was less than the RATEi value, or even negative. The lower RATE1 value indicates that the initial deterioration was more rapid and slowed down in the years following the first deck condition survey. The negative results indicate that one of the deck condition surveys may not have been conducted properly. A poor ground may have been used for the corrosion potential tests, or perhaps there were large variations in the deck temperature between the two tests. The presence of moisture is also an important factor as a very dry concrete deck will result in lower corrosion potential measurements. This is clearly one of the drawbacks of relying so heavily on the results from the corrosion potential tests. The negative rates were not used in the study. If the value of RATE1 was negative or lower than RATEi, a secondary rate, RATE2, was calculated and used.

3/ RATE2 - is the difference in the percentage of the deck area with corrosion potentials more negative than -0.35 V from the second condition survey divided by the age at the time of the second condition survey (nomenclature from Table 5.1, [BPOTEN1/(Y_S_C_S_- YR_CONS)]). RATE2 was only calculated if RATE1 was less than RATE_i or negative. RATE2 was often less than the RATE_i but was still utilized by proportioning the two rates in order to extend the data across as many of the five year divisions as possible.

CHAPTER 7

CURVE APPLICATION AND DISCUSSION

Chapters 5 and 6 outlined the steps taken to develop the database and the deterioration curves. In all cases, the deterioration is defined as the percentage of the deck area undergoing active corrosion at the time of measurement. Three sets of deterioration curves were developed to facilitate the estimation of future deterioration of Ontario bridge decks:

- 1/ Deterioration versus Age
- 2/ Deterioration and Concrete Cover Contours
- 3/ Rate of Deterioration versus Age.

All of the curves take into account two separate factors which influence deterioration:

- 1/ Deck surface protection i.e. exposed concrete decks, asphalt covered decks, or asphalt with waterproofing decks
- 2/ age of the structure

The two latter deterioration curves also take into account the effects of different depths of concrete cover. Subgroups were derived based on the average concrete covers to the reinforcing steel.

7.1 Deterioration versus Age

The correlation coefficients for all the curves developed through linear regression analyses are close to zero. This indicates that the relationship between age and the percentage of bridge deck area undergoing active corrosion is not linear for the data collected. The exposed concrete and the asphalt covered decks yield better results than did the asphalt with waterproofing data group. The shape of the curves indicate that the deterioration process begins relatively slowly but increases rapidly once a certain level of deterioration is reached. The rate of deterioration of a bridge deck will appear to slow down as more of the deck deteriorates, less area available for deterioration. Therefore the expected shape of a deterioration curve would be in the form of an "S". The only deterioration curve that resembles this S-shape is the one for the exposed concrete deck protection group.

For the exposed concrete deck group, Figure 6.1 (a), initial deterioration begins to accelerate at ten years of age, with only 4% of the deck area undergoing active corrosion. The curve becomes steeper at approximately 16 years of age when 15% of the deck area is actively corroding. The deterioration begins to slow after 20 years of age at which point 29% of the deck area is actively corroding.

For the asphalt covered decks, Figure 6.2 (a), two deterioration curves were developed. Curve 1 does not show accelerated corrosion until approximately 25 years of age when just less than 5% of the deck is actively corroding. This curve indicates that deterioration accelerates rapidly and continuously. Curve 2 illustrates a much slower rate of deterioration with deterioration not beginning until 35 years of age. At this point,

deterioration steadily accelerates until 50 years of age and a corresponding 32% of the deck area is undergoing active corrosion. The existence of this second curve indicates that age is not the only determining parameter when estimating the extent of deterioration of asphalt covered decks. An explanation for the existence of this second curve is that older bridge decks were constructed and designed with one mat of reinforcing steel placed in the centre of the slab thickness. The newer bridge decks are constructed and designed with two layers of reinforcing steel in a slightly thicker deck. The actual concrete cover achieved to the reinforcing steel is larger for the older decks than for the newer decks as the internal environment is more crowded in the newer decks. The smaller cover in the newer decks means earlier chloride contamination at the level of the reinforcing steel and higher percentages of the deck area undergoing active corrosion.

It is interesting to note that deterioration accelerates at approximately the same percentage of deck area, 5%, as when the type of rehabilitation recommended is patch, waterproof and paving. This is the case for both the exposed concrete and asphalt covered (curve 1) decks. As expected this point is reached later than for exposed concrete decks. Another important point is that for both these deck surfaces, the deterioration levelled off approximately 10 years after it began.

The asphalt with waterproofing membrane decks, Figure 6.3 (a), also yielded two deterioration curves. The development of the two curves indicates that some decks were waterproofed earlier than others and perhaps some types of waterproofing worked better than others or the applications of the membranes are better in some Districts. The explanation of larger concrete covers to the reinforcing steel for the older bridge decks

as explained in the previous paragraphs may also be relevant for the asphalt with waterproofing decks. It was not possible to separate the waterproofed decks into age groups of when the waterproofing membranes were applied to the decks as this data was not available.

Figures 6.1 (b), 6.2 (b) and 6.3 (b) illustrates that exposed concrete decks deteriorate quicker than the asphalt and asphalt with waterproofing decks. There is a 68% (one standard deviation) probability that deterioration will occur on an exposed concrete deck within 14 to 20 years of construction. Whereas, both groups of protected decks, asphalt and asphalt with waterproofing, deteriorate later, 19 to 37 years and 18 to 40 years after construction, respectively.

7.2 Deterioration Contours

The multiple regression analyses conducted to develop the Deterioration and Concrete Cover Contours yielded higher correlation coefficients. This indicates that the relationship between both concrete cover and age to the percentage of bridge deck undergoing active corrosion is more linear than the relationship of the level of deterioration with only age. Two sets of contours have been derived for all three deck surfaces:

Set A - the contour lines developed represent different percentages of deck area undergoing active corrosion (5, 10, 20, and for the asphalt and asphalt with waterproofing groups 30%)

Set B - the contour lines developed represent different concrete covers to the top layer of deck reinforcement (20, 40, 60, 80, and 100 mm).

The progression of these contour lines to the right follows engineering logic. As concrete

The progression of these contour lines to the right follows engineering logic. As concrete cover increases, the expected corrosion activity at the top layer of reinforcement at a specific age decreases. Likewise, as age increases the expected corrosion activity increases for a specified cover. The slopes of the contour lines also follows the expected progression as the steepest slope (fastest deterioration rate) is illustrated in the exposed concrete deck group and the flattest (slowest deterioration rate) is illustrated by the asphalt with waterproofing deck group. The calculated slopes for the percentage deck area undergoing active corrosion contours are as follows (Figures 6.4 (a), 6.5 (a), 6.6 (a)):

- exposed concrete, $m = 15.71 \text{ mm/yr}$.
- asphalt covered, $m = 4.04 \text{ mm/yr}$.
- asphalt with waterproofing, $m = 1.77 \text{ mm/yr}$.

Where "m" represents the slope of the contour line. The units of these slopes, mm/yr are the units of concrete cover and age. This does not permit deterioration rate interpretations which would be measured as percentage deck area (undergoing active corrosion) per year. Deterioration rate interpretations can be measured if the concrete cover deterioration contours are used (see Figures 6.4(b) to 6.6(b)) where the units of the slope of the contour lines are in percentage deck area undergoing active corrosion per year. The calculated slopes of these concrete cover contour lines are as follows:

- exposed concrete, $m = 2.2 \text{ \%/yr}$.
- asphalt covered, $m = 1.9 \text{ \%/yr}$.
- asphalt with waterproofing, $m = 0.6 \text{ \%/yr}$.

To determine the deterioration of a specific bridge deck, the average concrete cover and the age of the bridge are required. This information is available in the DART surveys. The expected level of deterioration (the amount of the bridge deck surface that is actively undergoing corrosion) can be estimated using either set of contour lines. This process can be used to assist engineers in their decisions as to which structures should be added to the rehabilitation program. The accuracy of the corrosion estimated is not high as the number of bridge decks available for analyses was relatively small. However, the curves can help enhance engineering judgement which is currently used as a decision tool for committing structures to the rehabilitation program.

The results from the regression analysis also indicates that the age of a bridge deck has a greater influence on the level of deterioration than the concrete cover to the reinforcing steel (higher coefficient). If average cover is estimated to be 50 mm, it will only take 4.6 years for a 10% increase in the percentage of the deck area undergoing active corrosion for the exposed concrete deck protection group. For asphalt covered decks it will take 5.2 years and 16.6 years for asphalt with waterproofing decks.

For an asphalt covered deck with an average concrete cover of 70 mm and 25 years of age, using the contour lines in set A, the expected percentage of deck area undergoing active corrosion of the reinforcing steel is approximately 7%. However, the standard error calculated for this regression line is 20.2%. Therefore the percentage of the deck actively corroding could be between 0% and 27.2% of the deck area. This wide range encompasses the percentage of deck area criteria for all three types of rehabilitations available. Hence, engineers interpreting this data need to be knowledgeable

about deterioration trends in the specific Ontario District in which the specific bridge deck is located.

7.3 Rate of Deterioration versus Age

The data gathered in the exposed concrete and asphalt covered deck groups developed more realistic curve shapes than for the asphalt with waterproofing deck data group. All but one of the asphalt with waterproofing curves corresponds to logic. In these graphs the data was divided into groups according to the average concrete cover to the reinforcing steel. Curves were developed for each of these concrete cover groups.

The age of the structure must be known to estimate future percentages of the deck area that will be undergoing active corrosion from these curves. If the average concrete cover to the reinforcing steel is known, a more realistic estimate can be made. To make estimates, the following steps must be taken:

- Average cover and age are taken from the information gathered from the detailed bridge deck investigation and DART surveys
- the appropriate set of curves for the type of deck surface is chosen. Note, for asphalt with waterproofing decks, the rate curves for asphalt covered decks can be used in conjunction with the asphalt with waterproofing curves and an average rate can be established between these two sets of curves
- enter the curve at the appropriate age, intersect the appropriate rate curve and connect a horizontal line to the y-axis and record the rate found as "R"
- in order to predict the actual percentage of the deck undergoing active corrosion

$$R = (P_{est.} - P_{meas.}) / (A_{est.} - A_{meas.}) \quad (7.1)$$

- where R = rate from y-axis
 Pest. = unknown
 Pmeas. = percentage of deck undergoing active corrosion, potential more negative than -0.35 V cse, in last detailed deck condition survey
 Aest. = age of the structure in the year where trying to estimate the percentage of the deck that will either require repair or that will be undergoing active corrosion
 Ameas. = age of the structure at the time of the last detailed condition survey.

The curve labelled "FINAL" represents a best fit overall rate of deterioration curve. This curve for all of the data collected within each deck protection group. Similarly, the average concrete cover shown is the average cover for all of the structures utilized within each protection group.

7.3.1 Exposed Concrete Decks

For exposed concrete decks, Figure 6.7, all the curves illustrated deterioration in a logically successive order. Bridge decks with lower concrete covers deteriorated more rapidly than decks with greater covers. The curve representing cover less than or equal to 50 mm is to the right of the curves representing decks with covers greater than 50 mm. This indicates faster deterioration rates for decks with less concrete cover to the reinforcing steel. The curves intersect at 16 years of age. This possibly indicates that after 16 years of age, the rate of deterioration is affected by factors other than concrete cover and age of the structure. The curves are similar to the beginning of an S-shaped

curve with the maximum rate of deterioration occurring at approximately 18 years of age, with a rate of deterioration between 2.2 %/yr. to 2.5 %/yr.

7.3.2 Asphalt Covered Decks

The curves in this deck protection group, Figure 6.8, also developed in a successively logical order. The rates calculated in Table E-2 after 27 years of age were not plotted as the number of data points with information in these age intervals was only 20 to 30% of the original number of data points available. The rates calculated in Table E-2 indicates that the rate curves for all the structures would take an unexpected dip at 37 years of age. This is likely due to the low number of data points available at this age.

The curve representing concrete covers greater than or equal to 100 mm plotted to the left of all of the curves. This indicates a greater rate of deterioration for greater concrete covers. This occurrence can be explained by the fact that not many of the structures used in this study fall into this concrete cover group. Therefore, only a small number of data points were available. As well, at depths greater than 100 mm, the corrosion potential test may lose some of its accuracy or the data may have been inadequately collected. Also, the bias of the data collected is evident as the detailed condition surveys were conducted only on structures which were scheduled for rehabilitation. Perhaps the structures which had concrete covers greater than 100 mm were added to the rehabilitation program as a result of paving contracts or similar rehabilitation work on other structures being conducted in the area.

The slope of the curves are relatively flat up to approximately 17 years of age and

a rate of deterioration of 5.0 %/yr. At this point, the slopes become steeper in almost a linear fashion.

7.3.3 Asphalt with Waterproofing Decks

The location of the curves relative to one another for this protection group, Figure 6.9, also follow reasonable logic. However, the data tabulated in Table E-3 is only plotted up to 27 years of age. The data tabulated after 27 years of age indicates that at 30 years, the less than or equal to 50 mm cover rate of deterioration falls below the rate of deterioration for all the structures regardless of cover. The rate of deterioration for this cover group then takes an extreme jump with an increase in the rate of deterioration to 5.75 %/yr. at 40 years of age. The rate of deterioration for concrete cover greater than or equal to 100 mm undergoes a large increase, up to 5.0 %/yr. within 2 years, after 33 years of age and a corresponding rate of 4.0 %/yr. Again, the rates calculated in Table E-3 after 27 years of age were not plotted as the number of data points with information in these age intervals was only 20 to 30% of the original number of data points available.

Implementing the three final rate curves would require Tables A1-1 to A1-4 of Part 3, Contract Preparation, of the Structure Rehabilitation Manual (see Appendix B, Figures B-5 and B-6) to be updated. When contracts are prepared at present, the quantity calculation for concrete removal is such that an increase of 10 % (1.1ⁿ) is assumed for every year between the year of the condition survey and rehabilitation. This 10% is added in order to take into account any deterioration that occurs during that period. From the Rate of Deterioration versus Age curves, a more accurate estimate may be obtained.

This would require estimators to use the curves and calculate "Pest." from equation 7.1. The curves developed indicate that the rate of deterioration is not linear. Rather, the rate varies depending on age, type of surface protection on the deck, and concrete cover.

The percentage increase in the rate of deterioration for the exposed concrete decks varies at 25 %/yr between ages of 8 and 10 years and 23 %/yr between 14 and 16 years. These figures were calculated using the FINAL curve which represents a best fit curve utilizing all the data in this protection group regardless of concrete cover. The FINAL curve within the asphalt covered deck group shows a percentage increase in the rate of deterioration of 8 %/yr between 13 and 17 years of age. This percentage increase in rate escalates quickly 17 years after construction. Between 23 and 27 years of age, the percentage increase in the rate is 20 %/yr. The percentage increase in the rates of deterioration for the asphalt with waterproofing protection group is also gradual in the earlier years. The increase between 13 and 17 years of age is only 8 %/yr whereas between 23 and 30 years of age the increase is 19 %/yr. These results indicate that the rate of deterioration is greatly reduced with deck protection. It is therefore felt that a standard increase of 10% is not an accurate assumption of the increase in deterioration that would occur within the time period previously specified.

CHAPTER 8

CONCLUSIONS and RECOMMENDATIONS

Approximately 8% of the Ontario bridge deck population that has been surveyed by a detailed deck condition survey has been included in the study conducted in this thesis. This represents approximately 131 structures. It is recognized that the database available was relatively small and perhaps too small to accurately assess the influences of traffic volumes, air entrainment, or the use of de-icing salts during winter maintenance programs on the deterioration process. Generally, the air entrainment study conducted within does support the well documented facts that air entrainment slows the deterioration process. The influence of the quantity of de-icing salts on the rate of the corrosion process could not properly be assessed as information on the amount of de-icing salts applied to the individual bridge decks was not available. As so little information was available, it was not possible to assess the relationship between traffic volumes and deterioration nor to conduct a proper comparison of deterioration rates within the various Regions of the province.

The curves developed and conclusions drawn can only be applied to bridge decks which serve their lives in a comparable environment. Ontario winters slow the deterioration process as the temperatures are too cold for the electrochemical corrosion

of the concrete reinforcement to progress. However, during these winter months bridge decks are subjected to large amounts of chlorides and cycles of thawing which encourage this corrosion process and contaminate the surface of the concrete with chlorides which can become active when warmer weather arrives. Also, Ontario is a relatively humid province where moisture is readily available for the electrochemical corrosion process to take place. Therefore, care should be taken in extrapolating the deterioration curves developed to other geographical locations.

8.1 Conclusions

8.1.1 Preliminary Studies

Three preliminary studies were conducted to assess the influence of traffic volumes, use of de-icing chemicals, and air entrainment on the amount of corrosion of the reinforcing steel. Unfortunately not all the structures had the proper data available for analysis in these preliminary studies. It was therefore not possible to effectively assess the influences of de-icing salts, AADT and air entrainment on the deterioration process of reinforced concrete bridge decks.

8.1.2 Deck Protection

The development of the three sets of deterioration curves, Deterioration versus Age, Deterioration Contours, and Rate of Deterioration versus Age, indicates that corrosion of the concrete deck reinforcement occurs more rapidly if the deck surface is

left unprotected. For the Deterioration versus Age curves, which consider the effects of age and type of deck protection on corrosion of the deck reinforcing, the exposed concrete decks indicated that 5% of the deck was undergoing active corrosion as early as 10 years after construction. Asphalt covered decks and asphalt with waterproofing decks did not reach this 5% level until 20 years after construction. Similarly, higher levels of corrosion were experienced at earlier ages for the exposed concrete decks.

The Deterioration and Concrete Cover Contours, which consider the effects of age, concrete cover, and the type of deck surface protection on the corrosion of the deck reinforcement gave similar results. The slope of the contour lines became flatter with increased protection of the concrete decks. This indicates that higher levels of deterioration are attained earlier for the unprotected decks, exposed concrete data group, and progressively later for the protected decks, asphalt covered and asphalt with waterproofing decks.

The Rate of Deterioration versus Age curves also indicate that the more protected the deck surface, the slower the rate of deterioration at the same structure age. A rate of 2.0 %/yr was reached after only 17 years of service life for the exposed concrete decks, but not until 27 and 33 years for the asphalt covered and asphalt with waterproofing decks respectively. It is therefore concluded here that the use of waterproofing membranes and asphalt wearing courses significantly improves the service life of concrete decks.

8.1.3 Factors Influencing Deterioration

The results from the various regression analyses conducted for all of the curves developed emphasized the strong influence of "age" on the progression of deterioration. All the coefficients for age as an independent variable were an order of magnitude larger than other independent variables included in the multiple regression analyses. The low value of the correlation coefficient for the first set of curves implies that the relationship between age and deterioration is not linear and other factors must also influence the deterioration of bridge decks in Ontario.

8.1.4 Ministry Policies

It is concluded here that the programs presently in place at the Ministry are effective in attempting to address the ever growing problem of deterioration of Ontario bridge decks. The Bridge Management Section's adoption of a benefit/cost analysis to ensure that budgets for rehabilitating structures are effectively spent is appropriate, as provincial funding for rehabilitations is not adequate to repair all deteriorated structures. Nevertheless, some method of prioritization must be utilized which considers both the level of deterioration of the bridge deck and the money available for rehabilitations.

8.2 Recommendations

Several recommendations can be drawn from the process of gathering data to the development of the deterioration curves in this study.

8.2.1 Utilization of Deterioration Curves

8.2.1.1 Rehabilitation Recommendation

It is recommended that two of the deterioration curves developed in this report (Deterioration and Concrete Cover Contours and the Rate of Deterioration versus Age) be included in Parts 2 and 3, Rehabilitation Selection and Contract Preparation, of the Structure Rehabilitation Manual, Reference 8. In selecting the time and method to rehabilitate a bridge deck, future deterioration trends must also be considered. In some cases, delaying rehabilitation will allow the deterioration to progress to the extent that a more costly rehabilitation would be required within a few years time. By interpreting future deterioration trends, through the use of both sets of these curves, prioritizing the order in which structures are rehabilitated may assist in preventing the need for costly future repairs.

8.2.1.2 Quantity of Repair

The Rate of Deterioration versus Age and Deterioration and Concrete Cover Contour curves can be used to more accurately estimate the quantity of concrete removals and patching required during rehabilitation contracts (Tables A1-1 to A1-4 Structure Rehabilitation Manual, see Appendix B). When contracts are presently prepared, the quantity calculation for concrete removal is such that an increase of 10% (1.1^n) is assumed for each year between the year of the condition survey and the rehabilitation. The curves developed indicate that for the exposed concrete decks, depending on the age

of the structure, 0.4 %/yr to 2.5 %/yr rate of deterioration can be expected. For the asphalt covered and asphalt with waterproofing decks, these rates are reached but at much later ages. This indicates that a standard increase of 10 %/yr is not an accurate assumption of the increase in deterioration that would occur within the two year period between the detailed condition surveys and the rehabilitation contracts. The shape of all of the Rate of Deterioration versus Age curves indicates that the deterioration process is not linearly related with time. Each type of deck protection should be assessed individually and the effects of the average concrete cover and age of the deck should be jointly considered. It should be said here that engineering judgement is, and will always be, an integral part of these decisions. These curves should be used by engineers as a tool to confirm decisions to commit structures to the rehabilitation program.

8.2.2 Information Storage System

Throughout the data collection stage, it was found that the Ministry's present filing system requires revisions. Files for many of the structures that were surveyed prior to 1985 were not easily located, and in some cases never found, by either Head Office or the Regional Offices. Better storage of structural records should be adopted. The District and Regional Offices of the Ministry should try to computerize their condition rating and detailed bridge deck condition surveys in such a way that pertinent information can be transferred to Head Office with minimal paperwork. The present mainframe database file OSIS (Ontario Structure Inventory System, Reference 29) should be revised to include the inspection fields utilized in this study.

8.2.3 Utilization of DBASE IV File

If adding the detailed deck condition survey information to OSIS is not possible due to restrictions in human resources and computing power, it is recommended that the DBASE IV file developed during the data collection for this study be used to store all detailed condition survey information beginning with the 1991 inspections. If the database file is distributed to each Region and staff members are properly instructed on input procedures, the detailed condition surveys could be input by Regional staff. Only the diskettes and a hard copy of the Regional summary would need to be sent to Head Office. Head Office could then review the surveys and keep the diskettes filed on a regional basis. This would reduce the amount of work required by Head Office and make the information readily available for sub-studies and setting the rehabilitation program. Regional staff could reduce their workload by requiring Consultants hired to conduct the detailed deck condition surveys to use the DBASE IV file for recording information. Drawings of the deck surface, and soffit deterioration, and the corrosion potentials could be submitted to the Region under separate cover or in the form of diskettes if CAD drawings are produced.

8.2.4 Maintenance Record Storage

Maintenance records should include the exact date and a documented description of the type of maintenance conducted so that the performances of the maintenance systems can be monitored.

8.2.5 Future Studies

It is recommended that another study be conducted utilizing the data presently collected which would involve analyzing the growth of the probable corrosion potential range. This range of corrosion potentials, which is measured during the detailed deck condition surveys, is the percentage of the deck area with half-cell measurements between -0.20 V and -0.35 V. As noted in Chapter 4, corrosion potentials in the range of -0.20 V to -0.35 V indicate an uncertainty as to whether or not corrosion activity is taking place. It appears as though the decks which recorded a drop in the active corrosion potential range had a large increase in the uncertain corrosion potential range. If "Total Corrosion Rate of Deterioration" curves are developed for the combinations of the percentage of the deck area in the uncertain range and in the active range of corrosion, subtracting the "total corrosion" rate curve from the active corrosion rate curve, the growth of the uncertain corrosion active range could be estimated. The growth of this range could then be related to the future rehabilitation needs of Ontario bridge decks. The final recommendation is that a larger study should be conducted which includes the information from all the structures that have been detail condition surveyed to date. This would entail computerizing the data from an additional 700 to 800 files. Data from an additional 600 structures would reduce the uncertainty of the curves presented. This was not done as part of this thesis as the time for the data collection was limited and this thesis concentrated on those structures which had been detail condition surveyed more than once.

In conclusion, this study can help the Ministry make better decisions on bridge

deck deterioration. In the past, these decisions have been made under both financial and operational restraints and on the basis of inadequate performance data. Sound engineering judgement, a systematic approach, consideration of all the parameters influencing deterioration, and an appreciation of available rehabilitation funds, are fundamental to identifying the most appropriate time and method to rehabilitate a bridge deck.

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- (20) HYMAN, W.A., O'CONNOR, D.S., 'Bridge Management Systems', Federal Highway Administration Demonstration Projects Division, FWHA-DP-71-01R, Washington D.C., October, 1989.
- (21) INGVARSSON, H., 'Bridge Operation and Maintenance Costs', Swedish National Road Administration, S-781 87 Borlange, Highway Prog. Analysis Off., Trends Overview, pp.199-204, 1987.
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APPENDIX A

**Figures and Tables Referenced from
Ontario Structure Inspection Manual
Ministry of Transportation, Ontario**

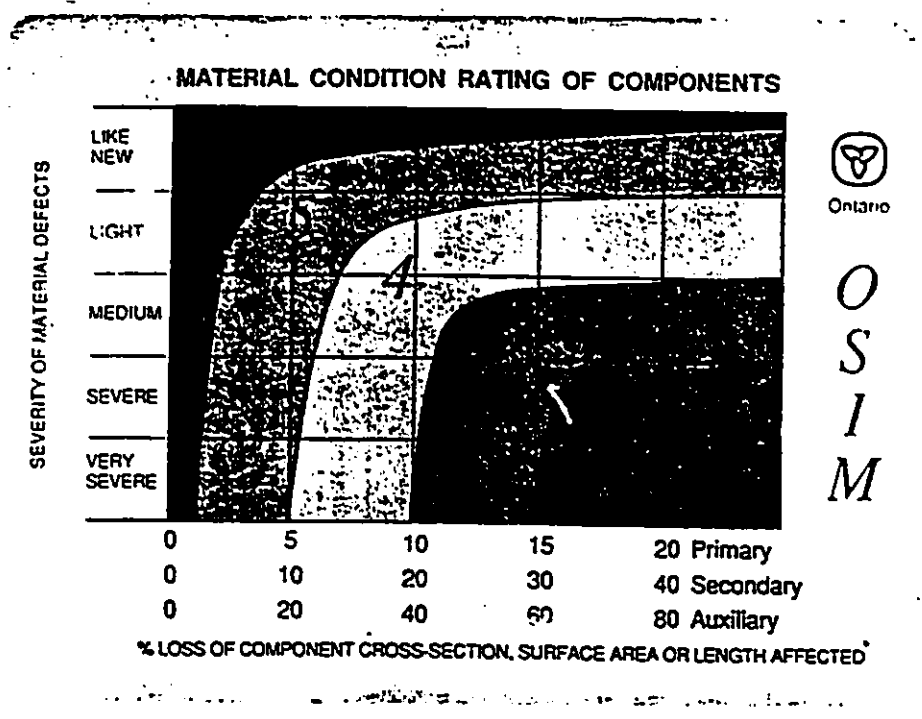


Figure 2.2 Material Condition Rating of Components

Figure A-1

Rating	Performance Condition of Components	Guidelines for Approximate Reduction in the Capacity of the Component to Perform its Intended Function		
		Primary Components	Secondary Components	Auxiliary Components
6	Very good	0 to 1%	0 to 2%	0 to 5%
5	Good	1 to 5%	2 to 10%	5 to 20%
4	Fair	5 to 10%	10 to 20%	20 to 40%
3	Poor	10 to 15%	20 to 30%	40 to 60%
2	Urgent, Inadequate	15 to 20%	30 to 40%	60 to 80%
1	Critical, Inadequate	Over 20%	Over 40%	Over 80%

Table 2.3 Performance Condition Rating of Components

Figure A-2

Material Condition Rating of Concrete Deck	Suggested Time Periods for Concrete Deck Condition Surveys
6	Condition survey not required for at least 8 years.
5	Condition survey required in 4 to 8 years.
4	Condition survey required in 1 to 3 years.
3	Condition survey required now.
2 and 1	May not have sufficient time to carry out condition survey.

Table 1.2 Suggested Guidelines for Concrete Deck Condition Surveys

Material or Performance Condition Rating	Suggested Time Periods for Repairs or Rehabilitation
6	Repairs should not be required for 10 years.
5	Repairs required in 6 to 10 years.
4	Repairs required in 3 to 5 years.
3	Repairs required in 1 to 2 years.
2	Repairs required within 1 year.
1	Repairs required immediately.

Table 1.3 Suggested Time Periods for Repairs or Rehabilitation

Figure A-3

APPENDIX B

**Tables Referenced from
Structure Rehabilitation Manual
Ministry of Transportation, Ontario**

TABLE 3.1 /Decision Matrix for Selection of Deck Rehabilitation Method

CRITERION	Patch, Waterproof and Pave	Latex Modified Overlay Only	Overlay Plus ¹ Waterproofing	Cathodic ² Protection	Comments
Total combined area of delaminations, spalls, medium to very severe scaling and corrosion potential more negative than -0.35 volts is between 0 to 5% of the deck area.	No	No	No	No	General maintenance repairs. In some cases patch, waterproof and pave may be considered.
Total combined area of delaminations, spalls, medium to very severe scaling and corrosion potential more negative than -0.35 volts is between 5 to 10% of the deck area.	Yes	No	No	No	Patching of small areas is much more economical than constructing a concrete overlay.
Total combined area of delaminations, spalls, medium to very severe scaling and corrosion potential more negative than -0.35 volts exceeds 10% of the deck area.	No	Yes	Yes	No	Patching of large areas is not economical.
Corrosion potential more negative than -0.35 volts over more than 20% of the deck area.	No	No	No	Yes	When the corrosion potentials are high, cathodic protection is needed to reduce the potentials.
Limited load capacity. Structure will not be replaced or strengthened to current bridge code requirements.	No	Yes	No	No	Latex overlay adds the least weight and is a structural component.
Areas of the deck with concrete cover to reinforcing steel less than 20 mm extend over 10% of the deck's surface area.	No	Yes	Yes	Yes	Additional concrete cover required to slow down ingress of chlorides. Increasing cover to current requirements will provide additional protection.

Figure B-1

	No	No	No	No	No	No	Do minimum amount of work.
Remaining life of structure less than 10 years.	No	No	No	No	No	No	
Wide cracks in deck slab.	Yes	No	Yes	Yes	Yes	Yes	Waterproofing membrane is required to bridge cracks.
Deck not waterproofed, or waterproofing system in poor condition, or exposed concrete wearing surface.	Yes	No	No	No	No	No	Waterproofing will prevent ingress of chlorides to rebar level.
Electrical power unavailable.	Yes	Yes	Yes	Yes	Yes	No	Power required for rectifier. Cathodic protection if mains, solar, wind or battery power can be provided economically.
Epoxy injection repairs previously performed.	Yes	Yes	Yes	Yes	Yes	No	Epoxy insulates underlying reinforcement from cathodic protection.
Grade or crossfall is greater than 4% on very flexible structures or 5% on other structures.	Yes	Yes	Yes	Yes	Yes	Yes	Caution: Latex modified concrete may be difficult to finish at required grade unless the slump is carefully controlled. Bituminous concrete may shove.
1	For additional guidelines for selecting the most suitable overlay plus waterproofing combination, see TABLE 3.2.						
2	For additional guidelines for selecting most suitable cathodic protection system, see TABLE 3.3.						
3	Capacity after rehabilitation must be verified. Additional strengthening may be necessary.						

Figure B-1 continued

TABLE 3.2 /Guidelines for Selecting the Combination of Overlay and Waterproofing Treatments

Traffic Volume per lane	Normal Concrete Overlay Plus Waterproof and Pave	Latex Modified Concrete Overlay Plus Waterproof and Pave	COMMENTS
AADT <10,000	All structures except round voided structures without transverse post-tensioning.	Round voided structures without transverse post-tensioning.	Latex modified concrete used on round voided decks without transverse post-tensioning because of its better performance over cracks.
AADT >10,000	Solid thick slabs.	All structures except solid thick slabs.	Additional cost of latex modified concrete is offset by increased service life and reduced traffic control costs. In solid thick slabs similar service life can be achieved with normal concrete overlay, and load capacity of solid thick slabs is not usually affected by the additional thickness.

Figure B-2

TABLE 3.3 / Guidelines for Selecting the Type of Cathodic Protection System

Type of CP System	Conductive Bituminous Overlay	Normal Concrete Overlay Plus Conductive Bituminous Overlay	Continuous Anode Embedded in a Conventional Concrete Overlay Plus Waterproof and Pave	COMMENTS
Criterion				
Concrete not properly air entrained or shows signs of scaling.	No	Yes	Yes	The Conductive Mix is porous and increases the possibility of freeze thaw damage to the deck concrete.
Wide cracks in deck slab.	No	No	Yes	Waterproofing membrana will bridge the cracks.
Area of spalls and delaminations less than 10% of deck area.	Yes	No	No	Patching is much more economical than a concrete overlay.
Concrete cover to reinforcing steel is less than 20 mm.	No	Yes	Yes	Low cover increases the possibility of "shorts" and uneven protection.
Prestressed deck slab.	Acceptable but not recommended	Yes	Yes	The concrete overlay slows water and chloride ingress to the prestressing. The waterproofing enhances this protection.

Figure B-3

Table 3.4/ Selection of Deck Rehabilitation Methods

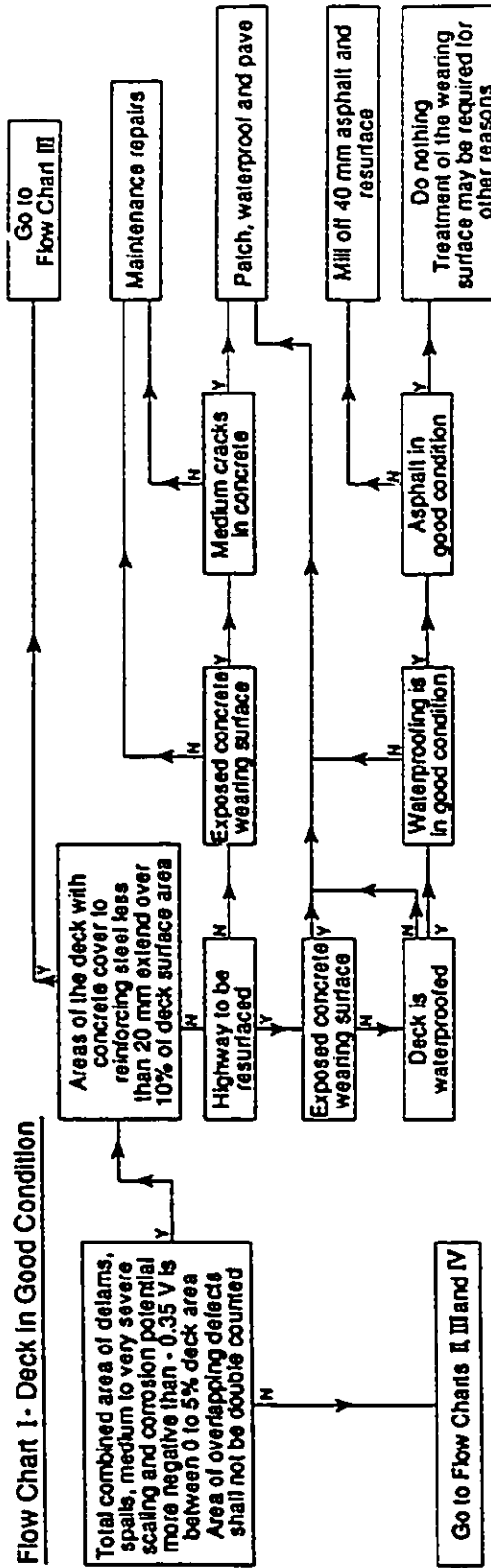


Figure B-4

Table 3.4/ Selection of Deck Rehabilitation Methods

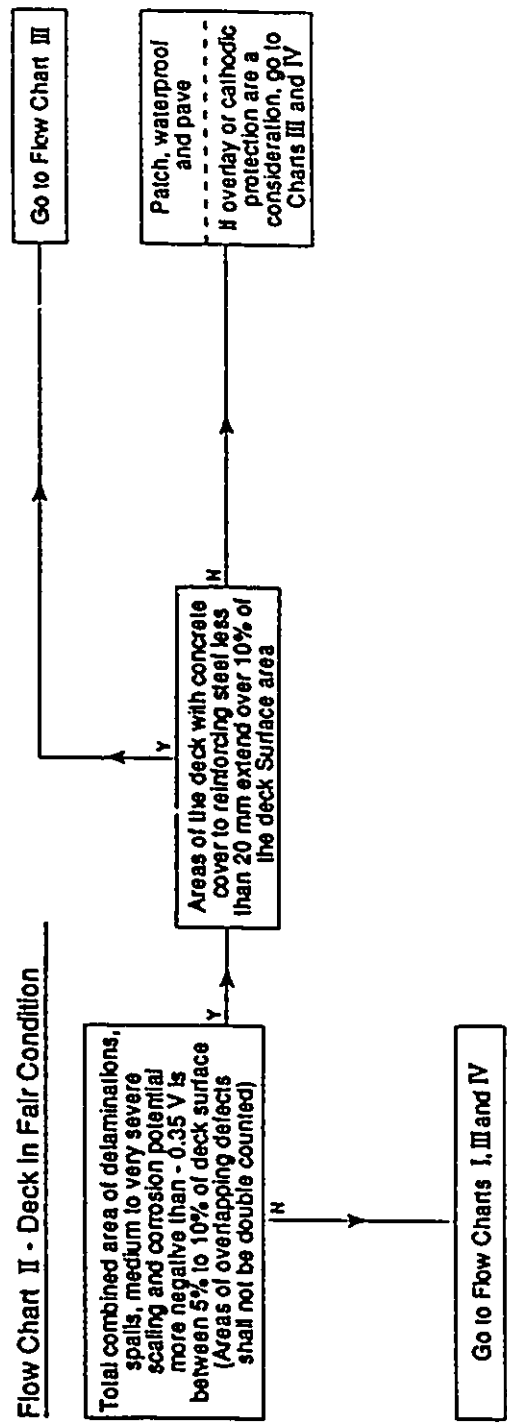


Figure B-4 continued

Table 3.4/ Selection of Deck Rehabilitation Methods

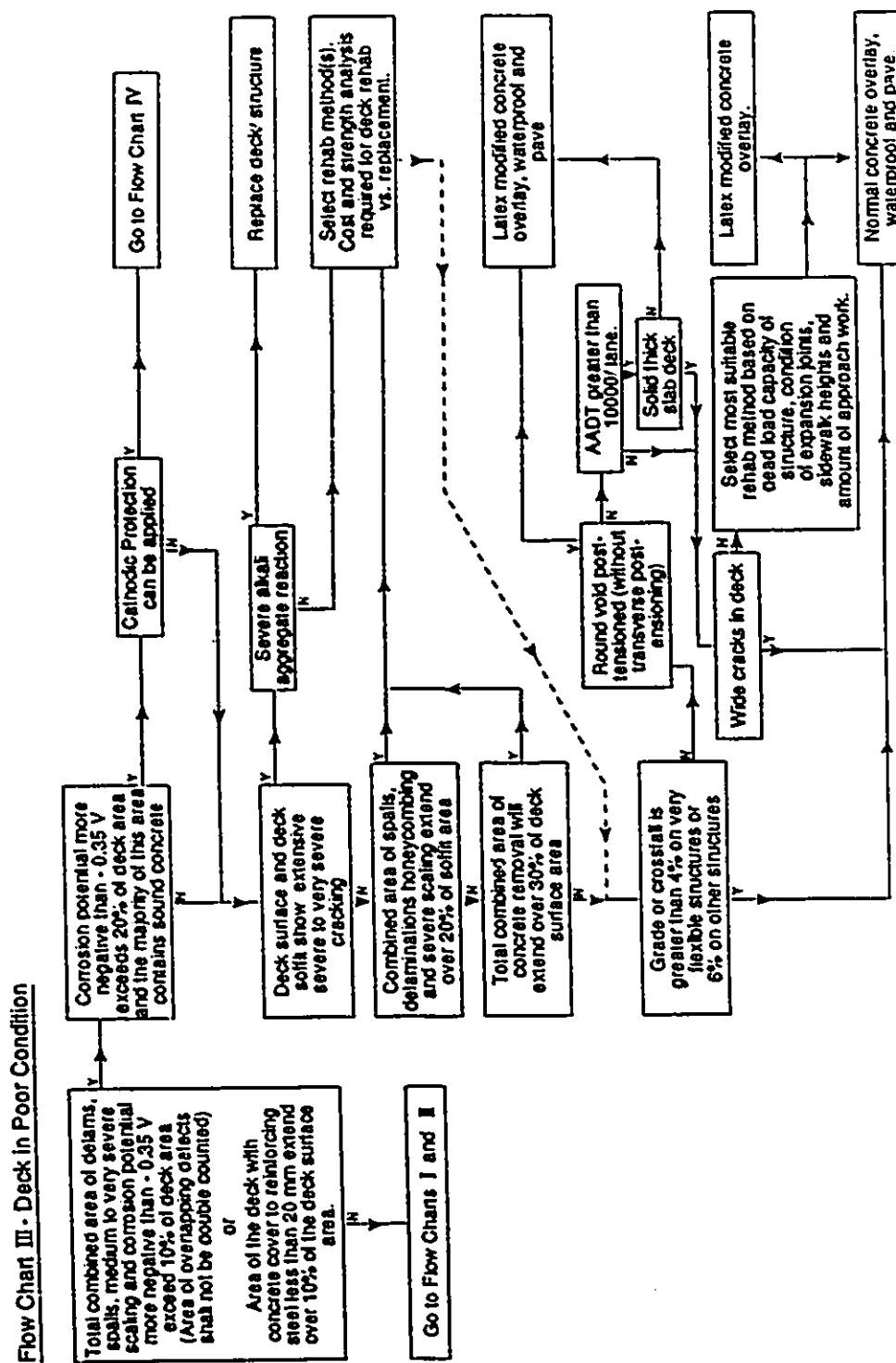


Figure B-4 continued

Table 3.4/ Selection of Deck Rehabilitation Methods

Flow Chart IV - Deck with High Corrosion Potentials Over Large Areas

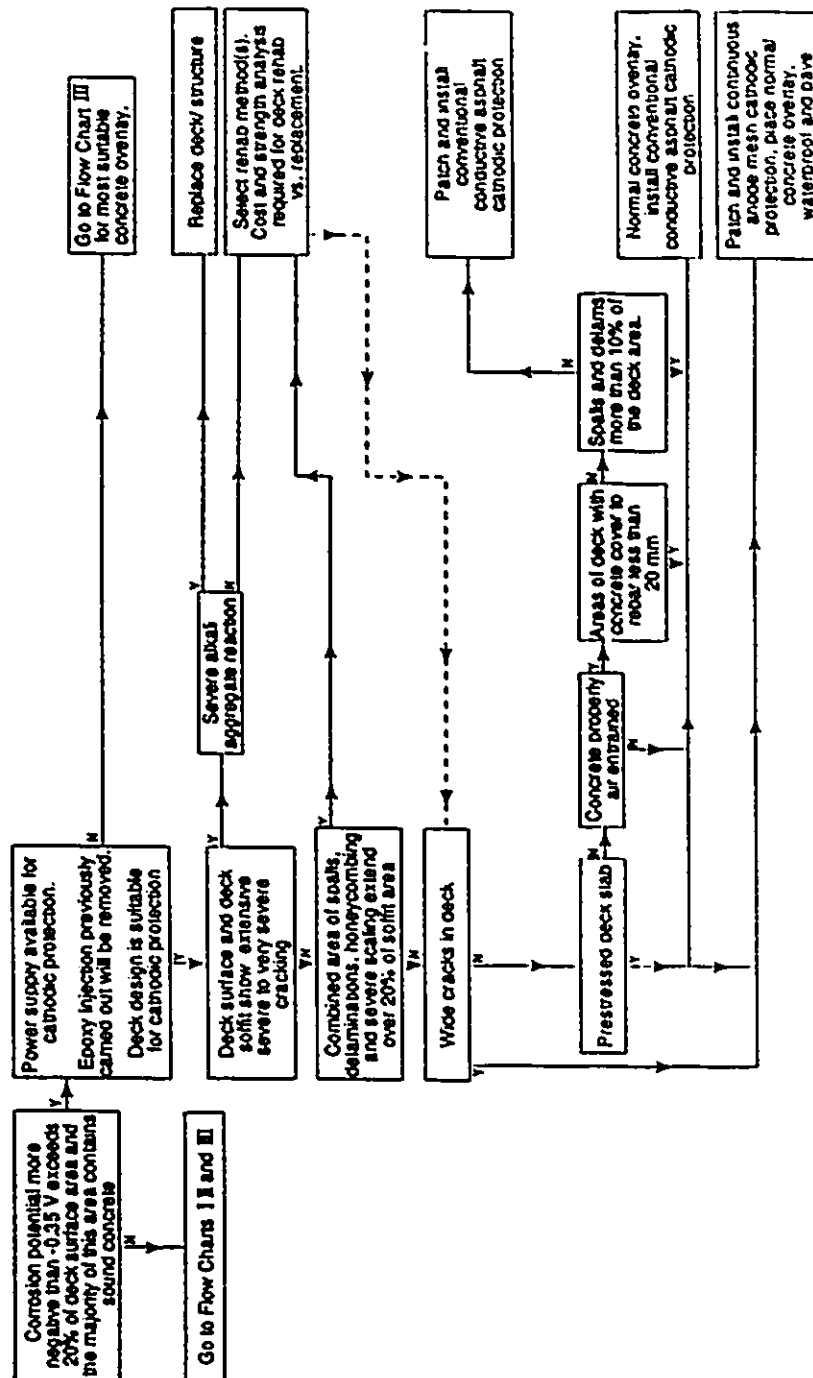


Figure B-4 continued

Table A1 - 1 - Exposed Concrete Decks
Concrete Removal Based on Corrosion Potential and Delamination Surveys
(Table shall not be used for cathodic protection rehabilitation)

Calculate A_{RER} , the area, m^2 , of concrete to be removed below rebar.*

$$A_{RER} = (A_{DLM} + A_{CP} - A_{LAP}) \times 1.1^n$$

Calculate V_{DK} , the volume, m^3 , of concrete to be removed from the deck.

$$V_{DK} = (A_{RER} \times D_{AVG}) + (A_{SCL} \times D_{SCL})$$

Table A1 - 2 - Exposed Concrete Decks
Concrete Removal Based on Delamination Survey

Calculate A_{RER} , the area, m^2 , of concrete to be removed to below rebar.*

$$A_{RER} = 1.1 A_{DLM} \times 1.1^n$$

Calculate V_{DK} , the volume, m^3 , of concrete to be removed from the deck.

$$V_{DK} = (A_{RER} \times D_{AVG}) + (A_{SCL} \times D_{SCL})$$

Table A1 - 3 - Asphalt Covered Decks
Concrete Removal Based on Corrosion Potential and Delamination Surveys
(Table shall not be used for cathodic protection rehabilitation)

Calculate A_{RER} , the area, m^2 , of concrete to be removed to below rebar.*

$$A_{RER} = 1.1 A_{CP} \times 1.1^n$$

Calculate V_{DK} , the volume, m^3 , of concrete to be removed from the deck.

$$V_{DK} = A_{RER} \times D_{AVG}$$

Figure B-5

Table A1 - 4 - Asphalt Covered Decks
Concrete Removal Based on Delamination Survey

Estimate A_p , the area, m^2 , of unsound concrete in area A_{CP}

Determine N_T = the total number of cores and sawn samples taken in area A_{CP} .

N_p = the number of cores and sawn samples indicating delaminated or deteriorated concrete in area A_{CP} .

Calculate $A_p = N_p/N_T \times A_{CP}$ (use a minimum value of 0.5 for N_p/N_T if insufficient cores or sawn samples have been taken)

Calculate A_{RER} , the area, m^2 , of concrete to be removed to below rebar.*

$$A_{RER} = [0.1 A_{CP} + A_p] 1.1^n$$

Calculate V_{DK} , the volume, m^3 , of concrete to be removed from the deck.

$$V_{DK} = A_{RER} \times D_{AVG}$$

Figure B-6

APPENDIX C

**Data Collection
DBASE IV File**

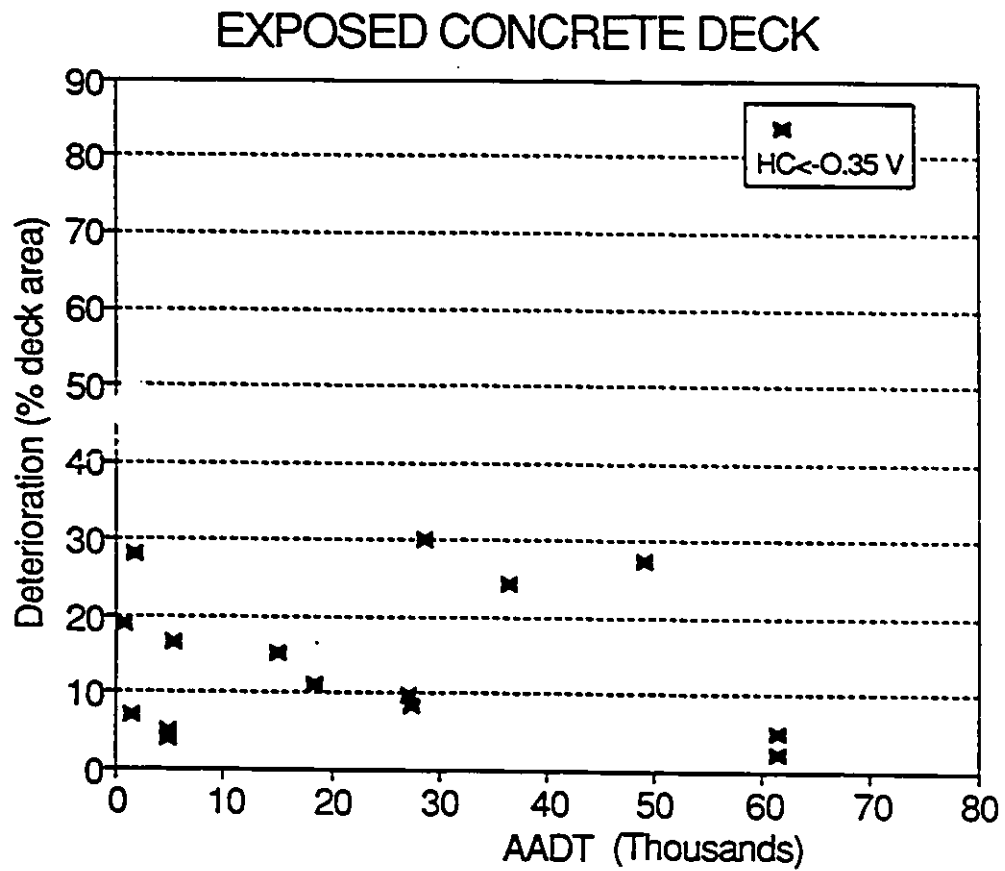


Figure C.1 Deterioration vs. AADT

ASPHALT COVERED DECK

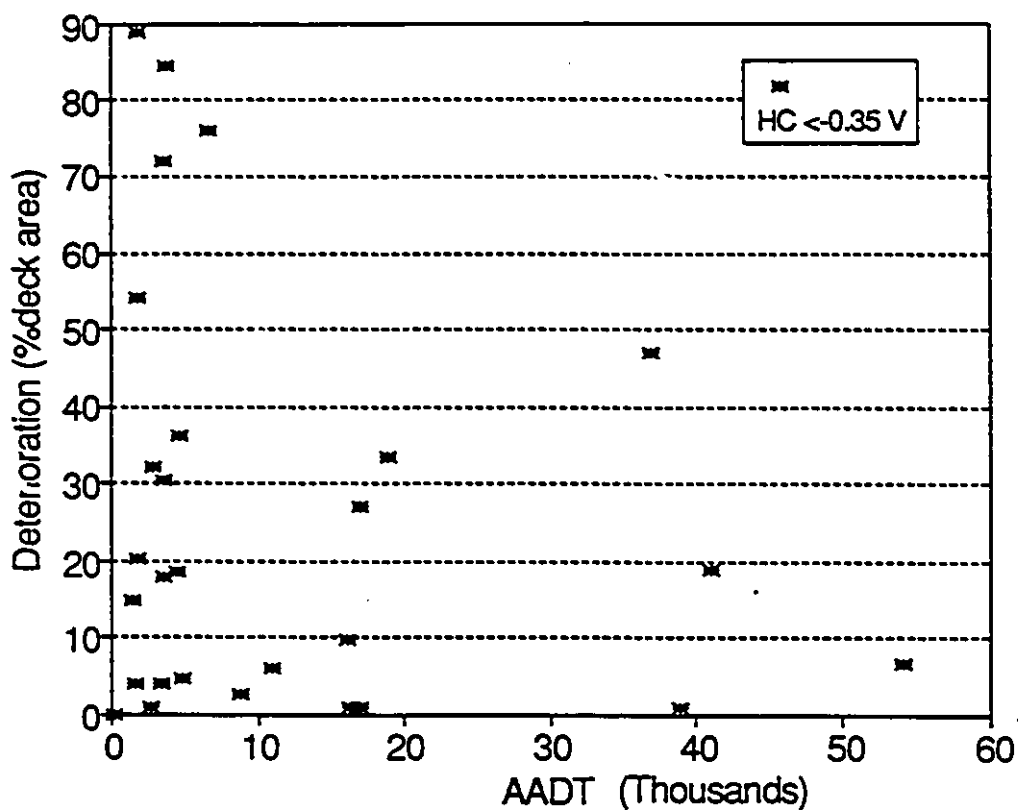


Figure C.2 Deterioration vs. AADT

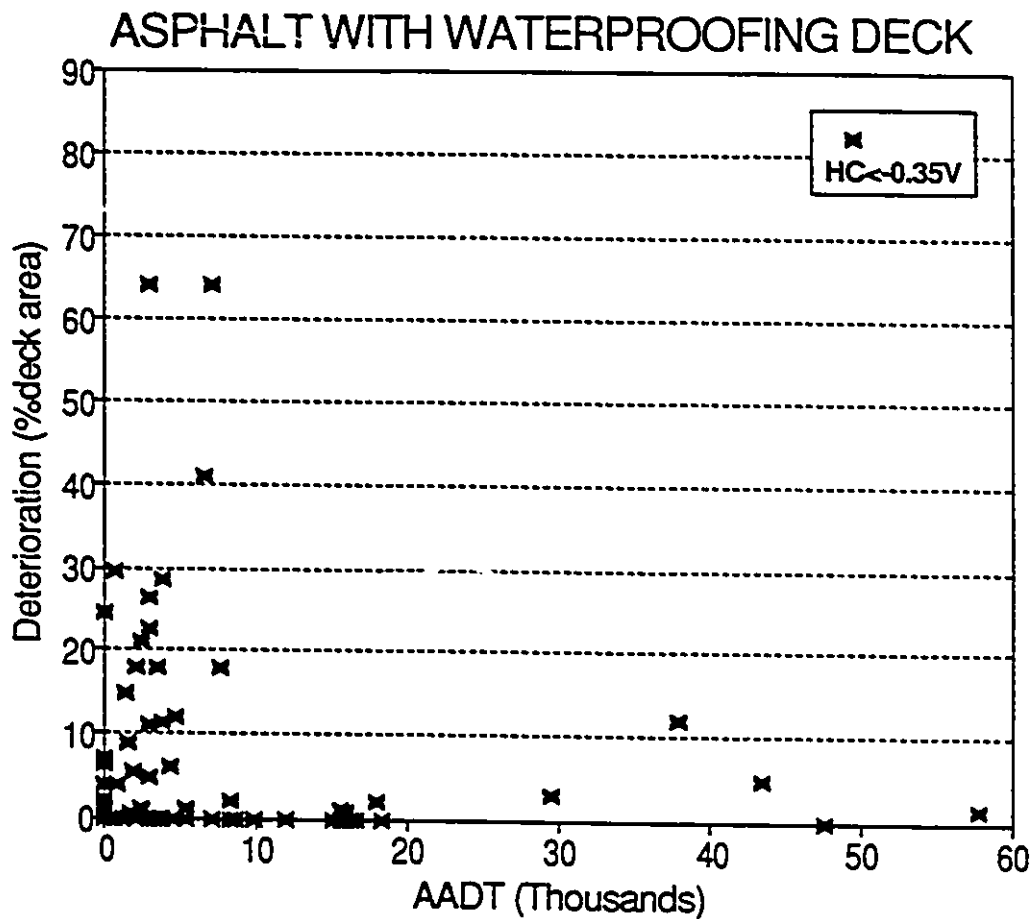


Figure C.3 Deterioration vs. AADT

PRINTOUT OF DATABASE

SITE	NAME	REG	DIST	HWY	AADT	YR_CONS	TYPE	HTYPE
09-042	BRIDGE OVR STONEY CK	C	4	3	2800	1964	2	PS ASSHTO GRDS
09-044	CNR OVERPASS(CAYUGA)	C	4	54	2350	1958	2	ST. GIRDERS
10-160	OAKVILLE CK. BR.	C	4	QEW	0	1936	9	RC. ARCH/T-BH
18-104	HENLEY BR.	C	4	QEW	41000	1939	9	RC. ARCH
18-191	OAKS RD U/P	C	4	QEW	0	1969	2	PS AASHTO GIRDS
18-192	ST. DAVIDS RD.(NO 8)	C	4	406	0	1968	3	PT VOIDED
21-074	MILL (PERCY) CK.	C	7	30	1650	1936	1	RF
21-159	HOLT RD. U/P	C	7	401	3327	1962	2	PS I-GIRDER
21-160	WAVERLY RD.	C	7	401	6726	1961	2	PS I-GIRDER
21-164	BENNETT ROAD U/P	C	7	401	634	1966	2	PS I-GIRDER
21-247	Hwy 45 Underpass	C	7	401	6500	1959	10	VOIDED THIK SL.
22-002	SEVERN R. BR.	C	6	169	3600	1957	1	RF
22-004	BLACK R.BR.(GREGG)	C	6	169	1800	1948	7	ST. BEAM/TRUSS
22-005	BLACK CK. BR.	C	6	169	1800	1955	2	ST. GIRDEMS
22-113	LYNDE CK. BR.	C	6	12	5300	1971	2	PS CONC.GIRDER
22-149	LYNDECK.BR.(WIDEN57)	C	6	12	6600	1929	6	T-BEAM (200 sl)
22-354	SEVERN R. OVERFLOW	C	6	169	1800	1971	1	RF
24-106	HUMBEN R. BR.	C	6	7	27400	1957	2	S.CT./PS .GIRD
24-211	CPR O/HD	C	6	50	17000	1961	2	CONC. BEAM/RCD
24-214	ETOBICOKE CK. BR.	C	6	7	28600	1971	1	RF
26-060	PETERBOROUGH.BVPS&CPR	C	7	7	3300	1958	2	ST. GIRDERS
26-061	OTONABEE R. BR.	C	7	7	8300	1958	2	ST. GIRDERS
26-081	CNR O/HD	C	7	7	7150	1958	2	ST. GIRDEL
32-065	TRENT CAVAL B.ROSEDL	C	7	35	2650	1962	2	ST. GIRDERS
34-033	VICTORIA AVE. U/P	C	4	420	0	1941	1	RF
34-193A	CNR O/HD	C	4	58 HBL	0	1967	3	PT VOID S'AB
34-210	COLLIER RD. U/P	C	4	406	15100	1968	2	AASHTO GIRDERS
36-034	Hwy. 6 RAMP U/P	C	4	403	0	1961	2	ST. GIRDER
36-096	MOHAWK RD. U/P	C	4	403	0	1968	3	PT VOIDED SLAB
37-194	KEELE ST.	C	6	401	43500	1964	2	ST. GIRDER
37-230	Hwy. 427 U/P, BURNHAMT	C	6	BURN.RD	0	1967	3	PT VOIDED SLAB
37-230	Hwy. 427 U/P BURN.RD	C	6	BURN.RD	0	1967	3	PT VOIDED SLAB
37-311 #5	400/401 INTER. BRG#5	C	6	401/400	0	1963	3	PT/SLAB
37-311 #8	401/400 INT. BRG.#8	C	6	401	0	1963	3	PT VOIDED SLAB
37-322	Hwy 401/DVP BR.#4	C	6	401 EBC	36420	1964	1	RF
37-324 #2	DON VALY/401 INT. #2	C	6	401	61360	1966	3	CONT. PT VOIDED
37-329 #5	DON VALY/401 INT. #5	C	6	401 EBC	61360	1965	2	PS/CONT. GIRDER
37-335	DON R. BR. # 2	C	6	401 EBC	57780	1964	2	ST. GIRDERS
37-341	M-Y RMP YG ST.EB/COL	C	6	401 EBC	241000	1964	1	RF
37-341	1-N RMP YG ST.EB/COR	C	6	401 EBL	241000	1964	1	RF

SITE	NO_SPAN	DECK_AREA	SURFACE	WPH	N_C_SURV	YEAR_F_C_S	YEAR_S_C_S	CONC_COVER	COMP_STR
09-042	1	158.6	ASPHALT	Y	2	1980	1985	45	67.5
09-044	3	408.4	ASPHALT	N	2	1980	1984	100	70.6
10-160	7	4172.4	ASPHALT	Y	2	1981	1985	55	55.0
18-104	6	3823.5	ASPHALT	N	2	1983	1985	60	77.7
18-191	4	893.2	CONCRETE	N	2	1984	1988	47	43.2
18-192	3	759.4	CONCRETE	N	2	1981	1988	55	66.1
21-074	1	211.2	ASPHALT	N	2	1985	1988	58	36.0
21-159	4	541.9	ASPHALT	N	2	1979	1988	16	45.5
21-160	4	588.7	ASPHALT	N	2	1979	1988	30	48.0
21-164	4	588.7	ASPHALT	Y	2	1979	1988	28	40.0
21-247	4	1435.0	ASPHALT	N	2	1987	1990	29	30.8
22-002	2	222.8	ASPHALT	N	2	1982	1987	59	53.3
22-004	1	211.6	ASPHALT	N	2	1982	1987	44	51.2
22-005	2	642.0	ASPHALT	N	2	1982	1987	42	46.7
22-113	1	313.9	CONCRETE	N	2	1984	1988	54	43.6
22-149	1	191.6	ASPHALT	Y	3	1981	1988	65	36.0
22-354	1	191.7	ASPHALT	N	2	1982	1987	71	43.5
24-106	3	1172.0	CONCRETE	N	2	1982	1987	47	48.8
24-211	8	933.0	ASPHALT	N	3	1982	1986	55	38.8
24-214	1	175.0	CONCRETE	N	2	1981	1987	72	46.0
26-060	3	514.3	ASPHALT	Y	2	1982	1985	53	44.7
26-061	11	2791.3	ASPHALT	Y	2	1980	1981	45	43.3
26-081	3	433.2	ASPHALT	Y	2	1982	1985	31	42.9
32-065	7	1573.6	ASPHALT	N	2	1978	1984	46	39.2
34-031	1	328.6	ASPHALT	N	2	1982	1987	125	63.4
34-193A	3	516.1	CONCRETE	N	2	1978	1988	60	62.1
34-210	3	669.0	CONCRETE	N	2	1983	1987	45	51.6
36-034	4	616.8	ASPHALT	Y	2	1982	1985	70	45.6
36-096	4	1918.9	CONCRETE	N	2	1982	1985	63	69.2
37-194	3	2947.2	ASPHALT	Y	2	1981	1988	33	39.4
37-230 EBL	3	1955.0	CONCRETE	N	2	1982	1985	67	63.8
37-230 WBL	3	1930.0	CONCRETE	N	2	1982	1985	63	53.6
37-311 #5	5	2950.0	CONCRETE	Y	2	1982	1985	49	71.1
37-311 #8	3	910.0	ASPHALT	Y	2	1982	1990	41	62.4
37-322	1	520.0	CONCRETE	N	2	1981	1986	86	48.8
37-324 #2	4	3879.0	CONCRETE	N	2	1981	1984	45	47.3
37-329 #5	3	679.4	CONCRETE	N	2	1981	1984	41	43.7
37-335	5	3060.0	ASPHALT	Y	2	1986	1986	0	50.0
37-341 EBC	1	293.2	CONCRETE	N	2	1986	0	80	49.4
37-341 EBL	1	403.4	CONCRETE	N	2	1982	1986	80	38.1

SITE	AIR_CONT	APOTEN1	APOTEN2	ACHLORIDE	DEPTHCLA	SPOTEN1	SPOTEN2	BCHLORIDE	DEPTHCLB
09-042	N	0.0	32.0	N	0	0.0	39.3	N	0
09-044	N	52.0	40.0	N	90	83.0	17.0	N	90
10-160	N	0.2	21.4	N	90	5.4	32.7	Y	30
18-104	N	16.4	55.8	Y	70	19.1	67.0	N	55
18-191	N	13.0	62.0	Y	50	0.0	0.0	N	0
18-192	Y	0.6	12.6	N	50	8.7	60.3	N	50
21-074	N	27.5	65.8	Y	0	84.5	15.5	Y	0
21-159	Y	0.0	0.1	N	10	4.0	20.6	Y	50
21-160	Y	0.0	0.0	N	0	3.7	37.5	N	0
21-164	Y	29.5	52.9	N	0	51.0	45.0	Y	90
21-247	N	48.6	45.8	Y	50	76.2	21.0	Y	50
22-002	N	24.4	37.2	Y	90	30.5	65.9	N	0
22-004	N	57.6	42.4	Y	0	88.9	11.1	N	0
22-005	N	32.0	38.3	Y	90	54.2	22.8	N	0
22-113	N	13.4	83.4	Y	0	16.5	76.0	Y	0
22-149	N	41.0	12.0	N	0	35.0	60.0	N	0
22-354	N	18.1	25.9	N	50	20.3	47.1	N	0
24-106	N	4.4	56.3	Y	0	8.4	71.6	Y	0
24-211	Y	6.7	77.0	N	0	1.0	52.0	N	0
24-214	Y	45.1	28.0	Y	0	76.4	23.4	N	0
26-060	N	0.0	0.0	Y	70	0.0	2.0	N	0
26-061	N	2.0	32.5	Y	70	16.2	57.4	N	0
26-081	N	64.0	36.0	Y	50	31.7	56.3	N	0
32-065	N	0.0	1.5	N	0	1.0	41.3	N	0
34-033	N	71.4	28.6	N	90	100.0	0.0	N	90
34-193A	N	19.7	70.0	N	50	30.2	56.2	N	30
34-210	Y	24.8	75.2	N	40	25.0	75.5	Y	50
36-034	N	0.0	27.0	N	0	0.3	27.3	N	0
36-096	N	4.3	55.8	N	20	15.3	67.1	N	20
37-194	N	5.0	5.8	N	10	0.6	16.5	N	0
37-230 EBL	Y	12.6	82.1	N	50	28.4	71.5	N	0
37-230 WBL	Y	9.6	63.5	Y	70	38.3	60.1	N	0
37-311 #5	Y	1.2	17.4	Y	90	0.0	0.0	N	0
37-311 #8	Y	1.5	15.7	N	0	0.0	0.0	N	0
37-322	Y	0.8	47.6	Y	90	24.3	68.6	N	0
37-324 #2	Y	0.9	30.0	Y	70	5.0	63.1	N	0
37-329 #5	Y	2.5	4.5	Y	50	2.5	15.9	N	0
37-335	Y	1.5	9.0	N	0	0.0	0.0	N	0
37-341 EBC	Y	36.3	63.7	Y	0	0.0	0.0	N	0
37-341 EBL	N	14.0	84.0	N	0	6.0	94.0	N	0

SITE	NAME	REG	DIST	HWY	AADT	YR_CONS	TYPE	KTYPE
37-723	E. MALL EBL/WBL	C	4	QEW	49000	1968	1	PS RF
37-805	401/407 INT. BRG #5	C	6	401/427	27180	1969	3	PT CIRC. VOID
03-039	RICHMOND RD U/P S	E	9	417 SBL	47600	1968	2	ST. PL. GIRDER
03-069	ALTA VISTA DR. U/P	E	9	417	38000	1959	2	SS. ST. BEAM
03-224	NICHOLAS ST. U/P	E	9	417	54000	1966	2	CONT. ST. BEAM
03-225	LEES AVE U/P	E	9	417	11000	1966	2	CONT. ST. PL. GRD
07-265	RUSSELL RD. O/P	E	8	38	15500	1969	2	PC CONC. I-GRDR
07-023	CPR O/H	E	8	38	2050	1937	1	CONT. RF
07-024	SHARBOT LK. CAUSEWAY	E	8	38	1450	1947	2	ST. BEAMS
07-054	COLLINS CK. BR. (EX48)	E	8	2	8300	1914	2	ST. BH/RF
07-055	WESTBROOK RD. U/P	E	8	401	0	1961	6	CONC. T-BEAM
07-056	WYDENHAM RD O/P	E	8	401 WBL	16300	1959	1	RF
07-059	CNR O/HD	E	8	15/401	0	1957	1	RF/CONC. BOXGRD
07-069	CATARAQUI R. BR.	E	8	401	15800	1954	6	R/F CONC. T
07-070	CNR O/HD	E	8	401	18000	1957	2	CT. RYTD/PL GRD
07-071	HWY 15 U/P	E	8	401	7000	1955	1	VOIDED RF
11-019	CROWE R. BR.	E	10	28	2000	1943	2	ST. BEAM/T PILE
11-164	CNR O/HD	E	8	401	16500	1956	2	ST. GIRDERS
11-174	BLESSINGTON CK. BR.	E	8	401	15500	1956	6	T BEAMS
11-220	CNR O/HD	E	8	49	1700	1964	2	SEM/CT. PS C.BM
11-257	CNR OVERHEAD BRG.	E	8	2	12000	1972	3	P/T VOID
16-018	KEMPTVILLE CK. BR.	E	9	43	3500	1956	1	CONT. RF
16-114	LANDONS BAY BR.	E	8	401	0	1940	7	PONY TRUSS
16-130	HWY 2 INTERCH U/P	E	8	401	3700	1959	1	RF/RC BOX GIRDER
16-137	HWY 16 U/I	E	9	401	4500	1961	5	CONC. BOX GIRDER
16-155	HWY 2 UNDERPASS	E	8	2/401	16000	1965	2	CONT. PL. GIRDER
17-058	REYNOLDS RD U/P	E	8	401	0	1966	2	SEMI/CT PS BEAM
17-061	NAPANEE RIVER BRIDGE	E	8	2	3500	1950	1	RF
17-065	NEWBURGH RD. U/P	E	8	401	0	1960	5	RF CONC. BOX GRD
17-074	BRANDON CK. BR. (WBL)	E	8	401	15750	1961	1	RF
17-077	WILTON CK. BR. (WBL)	E	8	401	15900	1961	1	RF
26-117	MILLHAVEN CK. BR.	E	8	401	16300	1960	1	RF
28-011	EEL'S CREEK BRIDGE	E	10	28	2400	1953	2	ST. BEAM
29-056	HAIGHTS CK BR	E	8	33	1800	1948	1	RF
31-020	SNAKE R. BR.	E	9	17	2900	1961	2	ST. BEAM
31-101	RIGAUD R. BR.	E	9	34	2800	1932	1	CONC. RF.
31-102	KIRBY CK. BR.	E	9	43	1400	1952	1	RF
31-126	PAYNE RIVER BR.	E	9	43	1700	1953	1	RF CONTINUOUS
31-210	BEAUDETTE R. BR.	E	9	34	4500	1934	1	CONC. RF.
	BROOKDALE AV. U/P	E	9	401	0	1962	6	CONT. T-BEAM

SITE	NO_SPAN	DECK_AREA	SURFACE	WPH	N_C_SURV	YEAR_F_C_S	YEAR_S_C_S	CONC_COVER	COMP_STR
37-341 EBL	1	403.4	CONCRETE	N	2	1982	1986	80	38.1
37-723	1	396.0	CONCRETE	N	2	1979	1989	50	53.2
37-805	4	1006.4	CONCRETE	Y	2	1982	1985	50	59.0
03-039 SBL	2	883.2	ASPHALT	Y	2	1979	1986	42	49.0
03-069	2	955.7	ASPHALT	Y	2	1980	1985	29	31.3
03-224	3	1641.2	ASPHALT	N	2	1980	1985	33	35.3
03-225	3	985.0	ASPHALT	N	2	1980	1985	36	38.2
03-265 EBL	5	879.9	ASPHALT	Y	2	1986	0	42	50.6
07-023	3	178.3	ASPHALT	Y	2	1981	1986	57	59.7
07-024	1	103.2	ASPHALT	Y	2	1981	1986	130	46.1
07-054	10	104.0	ASPHALT	Y	2	1981	1986	75	33.3
07-055	4	495.4	ASPHALT	N	2	1982	1986	48	57.3
07-056 MBL	1	115.6	ASPHALT	N	2	1981	1986	75	25.6
07-059	1	493.9	ASPHALT	Y	2	1981	1986	31	30.0
07-069	3	1740.5	ASPHALT	Y	2	1986	0	45	41.5
07-070	3	2398.2	ASPHALT	Y	2	1981	1987	46	33.2
07-071	1	589.0	ASPHALT	Y	2	1984	1990	42	26.9
11-019	5	323.7	ASPHALT	Y	2	1981	1985	42	26.7
11-164	3	1080.0	ASPHALT	Y	2	1981	1987	79	36.2
11-174	1	382.2	ASPHALT	Y	2	1981	1987	80	38.3
11-220	3	441.0	ASPHALT	N	2	1981	1988	44	28.2
11-257	4	921.0	ASPHALT	Y	2	1982	1990	68	43.0
16-018	2	393.0	ASPHALT	N	2	1980	1987	61	23.0
16-103	1	264.1	ASPHALT	Y	2	1981	1986	36	20.8
16-114	1	575.7	ASPHALT	Y	2	1981	1988	44	26.7
16-130	1	611.0	ASPHALT	N	2	1979	1987	47	33.6
16-137	4	934.6	ASPHALT	N	2	1981	1990	49	30.5
16-155	4	655.3	ASPHALT	Y	2	1982	1986	40	43.1
17-058	2	277.0	ASPHALT	Y	2	1981	1990	89	32.5
17-061	1	300.7	ASPHALT	N	2	1981	1986	70	32.3
17-065 MBL	1	93.2	ASPHALT	Y	2	1981	1986	63	16.5
17-074 MBL	1	250.0	ASPHALT	Y	2	1981	1986	80	20.5
17-077 MBL	1	189.7	ASPHALT	Y	2	1981	1986	69	29.9
26-117	1	194.3	ASPHALT	Y	2	1984	1990	45	43.0
26-011	1	93.2	ASPHALT	N	2	1980	1987	110	54.5
29-056	1	225.1	ASPHALT	Y	2	1984	1988	41	37.6
31-020	1	109.3	ASPHALT	N	2	1981	1988	275	30.0
31-101	1	149.1	ASPHALT	N	2	1980	1987	70	31.9
31-102	2	386.0	ASPHALT	Y	2	1980	1987	70	35.2

SITE	AIR_CONT	APOTEN1	APOTEN2	ACHLORIDE	DEPTHCHLA	BPOTEN1	BPOTEN2	ECHLORIDE	DEPTHCHLB
37-723	N	19.4	76.3	Y	50	27.5	68.2	N	30
37-805	Y	5.6	60.0	Y	90	9.6	83.2	N	0
03-039	N	0.0	0.0	N	0	3.9	17.4	N	50
03-069	N	12.0	85.0	Y	90	57.4	42.6	N	0
03-224	N	0.0	42.0	Y	90	6.7	45.5	N	0
03-225	N	0.0	1.0	N	20	6.2	33.1	N	0
03-265	Y	1.0	16.9	N	30	0.0	0.0	N	0
07-023	N	0.0	30.0	Y	50	2.4	93.6	N	0
07-024	N	9.0	82.0	N	90	59.0	41.0	N	0
07-054	N	0.0	61.0	Y	90	0.0	95.0	N	0
07-055	N	0.0	0.0	N	10	0.0	0.0	N	0
07-056	N	0.0	3.0	Y	90	1.0	76.0	N	0
07-059	N	1.0	26.5	Y	90	19.0	52.0	N	0
07-069	N	0.9	20.9	N	0	0.0	0.0	N	0
07-070	N	2.0	29.0	Y	90	5.0	53.0	Y	90
07-071	N	0.0	0.0	N	0	2.0	16.5	Y	50
11-019	N	17.9	82.1	Y	90	56.5	43.5	N	0
11-164	N	0.0	13.5	N	10	1.0	54.0	N	20
11-174	N	0.0	51.5	Y	90	1.3	68.9	Y	90
11-220	N	0.0	2.5	Y	90	4.0	39.0	Y	70
11-257	Y	0.0	0.0	N	0	0.0	0.7	N	0
16-018	N	7.0	93.0	Y	90	72.0	28.0	Y	70
16-103	N	0.0	16.7	Y	90	14.7	32.9	N	0
16-114	N	0.0	6.3	Y	90	4.3	61.5	Y	90
16-130	N	4.0	23.2	Y	90	18.8	20.9	Y	90
16-137	Y	0.0	1.0	N	0	0.0	0.0	N	0
16-155	Y	24.4	60.6	Y	90	18.0	71.0	N	0
17-058	N	0.0	46.8	Y	90	15.0	80.0	N	50
17-061	N	0.0	8.5	N	10	7.0	17.0	N	0
17-065	Y	0.0	9.0	Y	90	0.0	66.0	N	0
17-074	Y	0.0	32.0	Y	90	10.0	74.0	N	0
17-077	N	0.0	9.0	Y	90	0.0	32.0	N	0
26-117	N	1.0	12.4	N	10	1.5	11.8	N	0
28-011	N	0.0	2.0	N	90	0.0	2.0	N	90
29-056	N	26.5	66.2	N	0	33.0	72.8	Y	0
31-020	N	0.0	60.0	N	90	32.2	67.8	N	50
31-101	N	0.0	100.0	Y	90	0.0	85.0	Y	90
31-102	N	0.6	73.4	Y	90	9.0	82.0	Y	90
31-126	N	0.0	72.0	Y	90	4.0	96.0	Y	70
31-210	Y	2.0	12.8	Y	30	8.8	53.9	N	0

SITE	NAME	REG	DIST	HWY	AA DT	YR_CONS	TYPE	HTYPE
31-232	HWY 2/34 U/P	E	9	401	2000	1963	5	CT. CONC. BOXGRD
31-241	BAINSVILLE RD. U/P	E	9	401	0	1964	2	PS CONCRETE BH
31-242	COUNTY RD#17 U/P	E	9	401	0	1964	2	ST. GIRDERS
31-243	CURRY HILL RD. U/P	E	9	401	0	1964	2	PS CONC. GIRDER
31-245	FORCED RD. U/P	E	9	401	0	1964	5	CT. CONC. BOXGRD
40-082	ANSON CK. BR.	NR	11	118	1400	1971	2	PS CONC. BEAM
42-079	SOUTH MUSKOKA R. BRG	NR	11	11	4650	1952	7	ST. TRUSS/2-STBH
42-149	BLACK CK. BR.	NR	11	118	1600	1972	2	PS/CONC. BEAMS
43-115	SPARKS CK. BR.	NR	13	17	3400	1959	1	RF/RC T-BEAM
44-018	SOUTH R. BR.	NR	13	654	650	1972	2	PS CONC. GIRDER
44-023	WASI R. BR.	NR	13	11	7700	1956	1	RF
44-065	SHAWANAGA RIVER BR.	NR	11	69	4250	1958	2	COMP/ST/PL GRDR
44-164	SEQUIN R. BR.	NR	11	69	5400	1961	2	ST. GIRDERS
38S-001	AGAWA R. BR.	NW	18	17	1500	1960	7	THROUGH TRUSS
38S-002	MONTREAL R. BR.	NW	18	17	1600	1958	2	ST. GIRDER
38S-256	BLIND R. BR.	NW	18	17	3500	1958	2	ST. PL. GIRDER
45E-074	BRG OVR NESTOR FALLS	NW	20	71	1050	1940	1	RF
48C-008	LOG RIVER BRIDGE	NW	19	17	700	1939	1	RF
48C-011	JACKFISH RIVER BRG.	NW	19	17	1850	1960	2	ST. PL. GIRDERS
48C-023	NORTH TROUT CREEK BR	NW	19	11/17	2800	1957	2	ST. BEAMS
48C-030	WOLF RIVER BRIDGE	NW	19	11/17	3600	1959	2	SLAB ON PR. BEAM
48C-098	COLDWATER CR. BRIDGE	NW	19	11/17	3800	1959	2	ST. GIRDERS
48C-100	CPR O'Head	NW	19	61	4750	1968	3	PT CONC.
48C-102	KAMINISTIOQUIA R. BRG.	NW	19	61	6950	1968	2	PS CONC. GIRDER
48E-008	ROSSLYN ROAD O/P	NW	19	61	4750	1968	3	PT
48E-027	STURGEON R. BR. #4	NW	19	11	900	1941	2	ST. BEAMS
48W-044	CEDAR CK. BR.	NW	18	17	1350	1957	1	RF
05-050	KAMINISTIOQUIA R. BR	NW	19	11/17	4300	1957	6	PRESTR. T-BEAM
05-186	UNION RD. U/P	SW	2	401	18350	1967	2	PS CONC. BEAM
06-059	LAWRENCE STATION U/P	SW	2	401	18350	1967	2	PS AASHTO BK
06-120	TURKEY CR.	SW	1	18	9800	1966	2	PL. GIRDER/COMP
12-058	CANARD CR.	SW	1	18	8600	1973	2	PS CONC. GRD/COH
12-059	BEIGRAVE BR.	SW	3	4	2900	1932	1	RF
12-060	MAITLAND R. BR.	SW	3	4	2900	1949	1	CONT. RF
14-233	MAITLAND R. BR. OVRFL	SW	3	4	2900	1950	1	CONT. RF
15-229	SYDENHAM R. BR.	SW	3	401	950	1957	7	THROUGH TRUSS
19-230	OXBOW RIVER (MELROSE)	SW	2	22	5400	1958	1	RF
19-369	MIDWAY CR. BRANCH BRG	SW	2	22	8800	1959	1	ST. GIRDERS
15-373	WELLINGTON RD U/P	SW	2	401	29500	1956	1	RF/CONC. BOX BK
	HWY :26 U/P	SW	2	401	15000	1961	5	MULTI-CELL BOX

SITE	NO_SPAN	DECK_AREA	SURFACE	WPH	N_C_SURV	YEAR_F_C_S	YEAR_S_C_S	CONC_COVER	COMP_STR
31-232	2	614.0	ASPHALT	Y	2	1979	1989	50	36.6
31-241	6	1043.0	ASPHALT	Y	2	1979	1986	35	37.0
31-242	4	1340.0	ASPHALT	Y	2	1979	1988	45	32.2
31-243	4	864.3	ASPHALT	Y	2	1981	1988	68	26.2
31-245	2	529.0	ASPHALT	Y	2	1979	1988	50	36.0
40-082	1	218.3	CONCRETE	N	2	1986	0	43	59.0
42-079	4	689.3	ASPHALT	Y	2	1981	1984	73	22.3
42-149	1	199.0	CONCRETE	N	2	1986	0	34	35.8
43-115	1	237.9	ASPHALT	Y	2	1983	1986	65	44.6
44-018	3	489.0	CONCRETE	N	2	1981	1987	44	34.5
44-023	1	153.0	ASPHALT	Y	2	1984	1988	75	44.6
44-065	1	323.0	ASPHALT	Y	2	1981	1985	51	30.6
44-164	3	730.6	ASPHALT	Y	2	1980	1986	57	0.0
385-001	1	989.9	ASPHALT	N	2	1980	1988	48	43.7
385-002	1	300.3	ASPHALT	N	2	1979	1988	59	51.8
385-250	1	403.7	ASPHALT	N	2	1985	0	38	50.9
415-074	0	155.1	ASPHALT	Y	2	1980	1989	80	63.7
45E-003	1	200.0	ASPHALT	Y	2	1980	1989	55	56.0
48C-008	2	483.0	ASPHALT	Y	2	1980	1985	45	30.4
48C-011	3	360.4	ASPHALT	Y	2	1980	1985	39	23.2
48C-023	1	281.1	ASPHALT	Y	2	1980	1989	46	43.3
48C-030	3	525.0	ASPHALT	Y	2	1980	1989	35	48.6
48C-098	3	565.1	CONCRETE	N	2	1985	1990	70	47.0
48C-100	4	1710.4	ASPHALT	N	2	1985	1990	41	39.0
48E-008	3	376.0	ASPHALT	N	2	1985	1990	93	44.2
48E-027	1	198.7	ASPHALT	Y	2	1979	1987	50	62.0
48W-044	1	1512.0	ASPHALT	Y	2	1982	1990	73	43.5
05-050	4	570.0	ASPHALT	Y	2	1980	1988	64	41.7
05-186	4	525.0	CONCRETE	N	2	1980	1987	40	45.2
06-059	3	582.2	ASPHALT	Y	2	1981	1990	39	49.6
06-120	4	1642.0	ASPHALT	Y	2	1984	1990	44	40.0
12-058	1	70.5	ASPHALT	Y	2	1985	1990	95	61.5
12-059	3	517.1	ASPHALT	Y	2	1985	1990	53	57.0
12-060	2	320.3	ASPHALT	Y	2	1985	1990	40	54.2
14-233	10	471.0	ASPHALT	N	2	1983	1987	35	60.8
19-229	1	270.0	ASPHALT	Y	2	1983	1988	35	43.9
19-230	3	608.0	ASPHALT	N	2	1983	1987	36	61.8
19-369	1	650.0	ASPHALT	Y	2	1983	1987	49	57.9
19-373	3	1050.0	ASPHALT	Y	2	1983	1987	40	50.7

SITE	AIR_CONT	APOTEN1	APOTEN2	ACHLORIDE	DEPTHCHLA	BPTEN1	BPTEN2	BCHLORIDE	DEPTHCHLB
31-232	Y	0.0	40.0	N	0	32.0	53.0	Y	90
31-241	Y	0.0	16.7	N	0	0.0	6.0	N	0
31-242	Y	0.0	7.0	N	30	0.2	9.4	N	10
31-243	Y	6.2	54.6	Y	50	55.1	44.7	Y	90
31-245	Y	0.0	17.0	N	10	0.0	36.0	N	10
40-082	N	2.7	52.0	N	0	0.0	0.0	N	0
42-079	N	12.0	12.0	N	0	22.0	51.4	Y	120
42-149	Y	13.0	55.0	Y	0	0.0	0.0	N	0
43-115	N	18.0	60.0	Y	0	25.0	60.0	Y	0
44-018	N	5.0	83.0	Y	0	19.0	53.0	Y	0
44-023	N	18.1	73.9	N	50	0.0	0.0	N	0
44-065	N	6.0	10.0	N	0	12.4	36.8	N	0
44-164	N	1.0	7.0	Y	50	1.8	14.6	N	0
385-001	N	2.3	14.9	N	50	15.0	60.0	Y	90
385-002	N	0.0	9.1	N	30	4.0	41.0	Y	50
385-25A	N	36.0	46.1	Y	0	0.0	0.0	N	0
415-074	N	0.0	83.0	Y	90	78.6	20.6	N	10
45E-003	N	0.0	12.2	N	30	7.5	84.5	Y	90
48C-008	N	5.4	74.4	Y	110	18.0	77.0	Y	90
48C-011	N	22.7	77.3	Y	90	82.0	18.0	Y	90
48C-023	N	11.4	76.0	Y	50	35.3	48.2	Y	50
48C-030	N	28.7	71.3	Y	70	69.2	12.9	Y	70
48C-098	Y	3.0	73.0	N	60	5.1	81.0	N	50
48C-100	Y	3.0	13.0	Y	70	4.7	26.8	N	0
48C-102	N	3.0	36.0	Y	90	4.1	44.3	N	90
48E-008	N	4.0	40.0	N	30	0.0	0.0	N	0
48E-027	N	15.0	85.0	Y	90	4.2	95.8	N	10
48H-044	N	2.7	15.0	N	30	1.1	24.4	N	0
05-050	Y	0.0	5.0	N	0	6.0	19.0	N	0
05-186	Y	0.0	4.0	N	30	11.0	88.0	N	0
06-059	N	0.0	0.0	N	30	1.0	6.0	N	0
06-120	Y	0.0	1.7	N	20	0.0	5.0	N	10
12-058	N	5.0	60.0	N	90	9.0	74.0	N	10
12-059	N	64.0	36.0	Y	110	64.0	36.0	Y	50
12-060	N	11.0	62.0	Y	90	26.0	59.0	Y	50
14-233	N	90.4	9.6	Y	90	92.1	7.9	N	0
19-229	Y	0.0	4.0	Y	70	1.0	11.0	N	0
19-230	N	2.9	17.7	Y	60	3.0	21.3	N	0
19-369	N	3.0	24.6	Y	80	14.0	47.0	N	0
19-373	N	0.0	20.0	N	0	4.0	47.0	N	0

SITE	NAME	REG	DIST	HWY	AADT	YR_CONS	TYPE	HTYPE
19-374	VICTORIA RD. U/P	SW	2	401	161	1961	1	RF/CONC.BOX
23-122	OXFORD CTY.RD 3 U/P	SW	2	401	0	1960	1	RF
30-208	INNISFIL TWP RD.	SW	5	400	350	1947	1	RF
33-148	GRAND R. HWY O/HD	SW	3	401	38800	1960	1	RF
33-149	CNR O/HD (WATERLOO#4)	SW	3	401	36950	1960	1	RF
33-150	HWY24 U/P S. (OLDSTR)	SW	3	401	19000	1959	5	CT.CONC.BOX GRD
33-151	REG. RD 36 U/P	SW	3	401	17000	1959	5	CONC. BOX GIRDR
33-175	AYR RD.U/P,CTY.RD.50	SW	2	401	4545	1959	6	RC/CONT. T-BEAM
33-176	CTY RD. 97 U/P	SW	2	401	0	1960	6	T-BEAM
33-177	WATERLOO RD #46 U/P	SW	2	401	0	1960	6	T-BEAM
35-005	S. SAUGEN R. BR.	SW	3	89	2350	1953	7	ST.THROUGH TRUS

SITE	NO_SPAN	DECK_AREA	SURFACE	WPM	N_C_SURV	YEAR_F_C_S	YEAR_S_C_S	CONC_COVER	COMP_STR
19-374	1	275.2	ASPHALT	N	2	1983	1988	70	52.5
23-122	2	313.5	ASPHALT	Y	2	1988	0	65	67.4
30-208	2	305.0	ASPHALT	N	2	1984	1987	130	42.4
33-148	1	496.0	ASPHLT	N	2	1984	1987	110	42.4
33-149	1	440.0	ASPHALT	N	2	1981	1987	130	62.5
33-150 SBL	4	1024.0	ASPHALT	N	2	1981	1987	53	47.0
33-151	4	521.3	ASPHALT	N	2	1984	1989	43	45.8
33-175	4	613.3	ASPHALT	N	2	1985	1988	57	57.4
33-176	4	732.0	ASPHALT	Y	2	1988	0	43	53.5
33-177	4	499.0	ASPHALT	Y	2	1988	0	48	43.2
35-005	1	275.7	ASPHALT	Y	2	1984	1988	38	56.6

SITE	AIR_CONT	APOTEN1	APOTEN2	ACHLORIDE	DEPTHCHLA	BPOTEN1	BPOTEN2	BCHLORIDE	DEPTHCHLB
19-174	N	0.0	0.0	N	0	0.0	0.0	N	0
23-122	N	7.0	33.0	Y	70	0.0	0.0	N	0
30-208	N	0.0	98.6	N	50	0.0	98.4	N	0
33-148	Y	0.0	22.6	N	70	1.0	56.0	N	0
33-149	N	1.0	34.4	N	10	47.0	53.0	N	0
33-150 SBL	N	10.6	65.4	Y	0	33.7	57.1	N	0
33-151	N	1.2	38.4	Y	90	27.0	65.0	Y	90
33-175	N	24.0	29.6	Y	0	36.1	42.8	N	0
33-176	N	0.0	30.0	Y	70	0.0	0.0	N	0
33-177	N	4.0	60.0	Y	50	10.0	63.1	N	0
35-005	N	21.0	54.3	Y	150	35.9	42.8	N	0

SITE	ADEL_AREA	BDEL_AREA
09-042	N/A	N/A
09-044	N/A	N/A
10-160	N/A	N/A
18-104	N/A	N/A
18-191	Delaminations = 76.9m = 8.6% Spalls = 0.5m Patches = 12.4 = 1.4% Total = 89.8m = 10%	
18-192	N/A	Delaminations = 51.15m = 6.7% Spalls = 22.16m = 2.9% Patches = 2.94m = 0.4% Total surface deterioration is 10% of deck area.
21-074	N/A	N/A
21-159	N/A	N/A
21-160	N/A	N/A
21-164	N/A	N/A
21-247	N/A	N/A
22-002	N/A	N/A
22-004	N/A	N/A
22-005	N/A	N/A
22-113	Delam. & spalls = 4.3m, 1.4% Patches = 4.2%	Delam. and spalls = 20.7m, 6.6% Patches = 5.2%
22-149	N/A	N/A
22-354	N/A	N/A
24-106	Delam. = 2.4%, spalls = 0.2% & patches 2%, most det. at east side of centre span.	Delam. = 1.8%, spalls = 0.2%, and patches 3.4% Most det. at east side of centre span.
24-211	N/A	N/A
24-214	Delam. & spalls = 16.5m = 9.4%	Delam. & spalls = 23.7m = 13.7%
26-060	N/A	N/A
26-061	N/A	N/A
26-081	N/A	N/A
32-065	N/A	N/A
34-033	N/A	N/A
34-193A	N/A	N/A

34-210	Delaminations = 14.8 = 2.2%	Delaminations = 9.85 = 1.5%
	Spalls = 3.5 = .52%	Spalls = .51 = .08%
	Patches = 3.6 = .54%	Patches = 19.16 = 2.9%
	Total = 3.3%	Total = 4.5%
36-034	N/A	N/A
36-096	Delaminations = 27.6m = 1.4%	Delaminations = 29.4 = 1.5%
	Spalls = 2.2m	Spalls = 2.9m
	Patches = 6.7m = 0.3%	Patches = 25.5m = 1.3%
	Total = 1.7%	Total = 2.8%
37-194	N/A	N/A
37-230 EBL	Delaminations = 66.4m = 3.6%	Delaminations = 50m = 2.6%
	Spalls and patches = 109.2m = 5.9%	Spalls = 1.7m
	Total deterioration = 9.5%	Patches = 41.5m = 2.1%
		Total = 4.7%
37-230 MBL	Delaminations = 74.5m = 4%	Delaminations = 102m = 5.3%
	Spalls and patches = 84.3m = 4.5%	Spalls = 5.2m = 0.3%
	Total = 8.5%	Patches = 57.8m = 3%
37-311 #5	N/A	Total = 8.6%
		N/A

SITE	ADEL_AREA	BDEL_AREA
37-311 #8	N/A	N/A
37-324 #2	Delaminations = 145m = 3.7% Spalls = 14m, patches = 12m, Total = 26m = 0.7%	Delaminations = 80.5m = 2% Spalls = 8.5m = 0.2% Patches = 16.5m = 0.4% Total = 2.6%
37-329 #5	Delaminations = 5m = 0.8% Spalls = 11m = 1.6%	Delaminations = 5 = .7% Spalls = 1.1 = .16% Patches = 2.3 = .34%
37-335	N/A	N/A
37-341 EBC	Delaminations, spalling and patches = 2.6%	N/A
37-341 EBL	Small areas of delam and asphalt patch=1.7%	Delam. area, no charge from 1982.
37-723	Delaminations = 29.4 = 1.5% Spalls = 2.9m Patches = 25.5m = 1.3% Total = 2.8%	N/A
039 SBL	N/A	N/A
069	N/A	N/A
0224	N/A	N/A
03-225	N/A	N/A
03-265 EBL	N/A	N/A
07-023	N/A	N/A
07-024	N/A	N/A
07-054	N/A	N/A
07-055	N/A	N/A
07-056 MBL	N/A	N/A
07-059	N/A	N/A
07-069	N/A	N/A
07-070	N/A	N/A
07-071	N/A	N/A
11-019	N/A	N/A
11-164	N/A	N/A
11-174	N/A	N/A
11-220	N/A	N/A
11-257	N/A	N/A
16-018	N/A	N/A
16-103	N/A	N/A
16-114	N/A	N/A
16-130	N/A	N/A

SITE	ADDEL_AREA	BDEL_AREA
31-243	N/A	N/A
31-245	N/A	N/A
40-082	N/A	N/A
42-079 NBL	N/A	N/A
42-149	Delam, only 1s.	N/A
43-115	N/A	N/A
44-018	N/A	N/A
44-023	N/A	N/A
44-065	N/A	N/A
44-164	N/A	N/A
38S-001	N/A	N/A
38S-002	N/A	N/A
38S-258	N/A	N/A
41S-074	N/A	N/A
45E-003	N/A	N/A
48C-008	N/A	N/A
48C-011	N/A	N/A
48C-023	N/A	N/A
48C-030	N/A	N/A
48C-098	Delam, < 1%.	N/A
48C-100	N/A	N/A
48C-102	Minor scaling and del. = 1% Spalls = 0.1m with ERB.	Delaminations = 1.67 = 0.3% Spalls = 0% Patches = 0.6 = 0.11% Total = 0.41%
48E-008	N/A	N/A
48E-027	N/A	N/A
48N-044	N/A	N/A
05-050	N/A	N/A
05-186	N/A	Delamination = 9m = 1.7%
06-059	N/A	N/A
06-120	N/A	N/A
12-058	N/A	N/A

SITE	REHAB_YR	RPOTENT1	RPOTENT2	REH_DEL	METHOD_REH
09-042	0	0.0	0.0	N/A	
09-044	0	0.0	0.0	N/A	
10-160	1989	0.0	0.0	N/A	SUBSTRUCTU
18-104	1987	0.0	0.0	N/A	RD
18-191	1988	20.6	0.0	Delaminations = 213M = 23.8% 95% of high corrosion potential areas were delaminated.	O/LAY(L+WP
18-192	1989	0.0	0.0	N/A	P.H.P.
21-074	0	0.0	0.0	N/A	RS
21-159	1989	0.0	0.0	N/A	O/LAY(N+WP
21-160	1989	0.0	0.0	N/A	O/LAY(N+WP
21-164	1989	0.0	0.0	N/A	CP(O/LAY)
21-247	0	0.0	0.0	N/A	CP
22-002	1989	0.0	0.0	N/A	O/LAY(N+WP
22-004	0	0.0	0.0	N/A	RD
22-005	1989	0.0	0.0	N/A	O/LAY(L)
22-113	0	0.0	0.0	N/A	
22-149	1988	0.0	0.0	N/A	
22-354	0	0.0	0.0	N/A	
24-106	1989	0.0	0.0	N/A	O/LAY(N+WP
24-211	1988	11.4	0.0	N/A	O/LAY(L)
24-214	1989	0.0	49.3	N/A	CP
26-060	0	0.0	0.0	N/A	
26-061	0	0.0	0.0	N/A	
26-081	1987	0.0	0.0	N/A	O/LAY(L)
32-065	1984	0.0	0.0	N/A	N/A
34-033	1989	0.0	0.0	N/A	O/LAY(N+WP
34-193A	1990	0.0	0.0	N/A	CP
34-210	0	0.0	0.0	N/A	
36-034	0	0.0	0.0	N/A	
36-096	0	0.0	0.0	N/A	
37-194	1989	0.0	0.0	N/A	O/LAY(L+WP
37-230	1989	0.0	0.0	N/A	O/LAY(L+WP
37-230 WBL	1989	0.0	0.0	N/A	O/LAY(L+WP
37-311 #5	0	0.0	0.0	N/A	
37-311 #8	0	0.0	0.0	N/A	
37-322	1987	0.0	0.0	N/A	CP
37-324 #2	0	0.0	0.0	N/A	
37-329 #5	0	0.0	0.0	N/A	
37-335	1988	5.1	10.0	Delaminations found over 24% of the deck surface.	N/A

SITE	REHAB_YR	RSPOTENT1	RSPOTENT2	REH_DEL	METHOD_REH
37-341 EBC	1988	31.0	69.0	Half cells taken at time of construction due to high area of delam. Half cells may be higher than expected because of low cover to rebars. Only S. 3/4 of deck area was investigated. Approx. 30% of delam. areas are outside areas of high corrosion potent.	CP
37-341 EBL	0	0.0	0.0	n/a	CP
37-723	1991	0.0	0.0	n/a	CP
37-805	1988	4.3	2.0	Area of removal of concrete based on the area of delamin. = 31m. Only did half cell potentials for half the deck surface.	O/LAY(N+HP)
03-039 SBL	1989	5.3	20.4	N/A	P.W.P.
03-069	1986	0.0	0.0	N/A	O/LAY(N)
03-224	1986	0.0	0.0	N/A	P.W.P.
03-225	1986	0.0	0.0	N/A	P.W.P.
03-265 EBL	1988	7.0	0.0	69m = 15.7% of deck delam. at time of constr. removal, based on half of deck area only. DC Pot2 not measured.	P.W.P.
07-023	0	0.0	0.0	N/A	P.W.P.
07-024	0	0.0	0.0	N/A	P.W.P.
07-054	0	0.0	0.0	N/A	O/LAY(N+HP)
07-055	1988	0.0	0.0	N/A	N/A
07-056 MBL	1988	0.0	0.0	N/A	O/LAY(L+HP)
07-059	1989	0.0	0.0	N/A	O/LAY(N)
07-069	1988	1.0	0.0	Delam. area removed = 145m, 21%	P.W.P.
07-070	1989	0.0	0.0	N/A	P.W.P.
07-071	0	0.0	0.0	N/A	O/LAY(N+HP)
11-019	1986	0.0	0.0	N/A	O/LAY(N)
11-164	1989	2.5	42.1	N/A	P.W.P.
11-174	1989	3.3	75.3	N/A	P.W.P.
11-220	1990	0.0	0.0	N/A	P.W.P.
11-257	0	0.0	0.0	N/A	O/LAY(N+HP)
16-018	1989	0.0	0.0	N/A	O/LAY(N+HP)

SITE	REHAB_YR	RPOTENT1	RPOTENT2	REH_DEL	METHOD_REH
16-103	1988	0.0	0.0	N/A	O/LAY (N+WP)
16-114	1990	0.0	0.0	N/A	P.W.P.
16-130	1989	0.0	0.0	N/A	P.W.P.
16-137	1990	9.7	72.0	N/A	N/A
16-155	1989	0.0	0.0	N/A	O/LAY (N+WP)
17-058	1990	15.0	80.0	N/A	N/A
17-061	1987	0.0	0.0	N/A	P.W.P.
17-065 HBL	0	0.0	0.0	N/A	
17-074 HBL	0	0.0	0.0	N/A	
17-077 HBL	0	0.0	0.0	N/A	
26-117	0	0.0	0.0	N/A	
28-011	1990	0.0	0.0	N/A	P.W.P.
29-056	0	0.0	0.0	N/A	
31-020	1990	0.0	0.0	N/A	O/LAY (N)
31-101	1989	0.0	0.0	N/A	P.W.P.
31-102	1989	0.0	0.0	N/A	P.W.P.
31-126	1989	0.0	0.0	N/A	P.W.P.
31-210	0	0.0	0.0	N/A	
31-232	0	0.0	0.0	N/A	
31-241	0	0.0	0.0	N/A	
31-242	0	0.0	0.0	N/A	
31-243	1989	0.0	0.0	N/A	
31-245	0	0.0	0.0	N/A	
40-082	1988	6.8	63.0	Delaminations were in areas of high corr. potent. Delam. was recorded over 6.6% of the deck area.	P.W.P.
42-079 NBL	1986	0.0	0.0	N/A	RD
42-149	1988	28.0	67.0	Delaminated areas were ,mainly in areas of high corr. potent. Found 33m of delamination. Removed 53m of concrete.	P.W.P.
43-115	1988	0.0	0.0	N/A	O/LAY (N+WP)
44-018	1988	0.0	0.0	N/A	O/LAY (N+WP)
44-023	1988	17.0	79.9	No drawings showing concrete removal available for comparisons.	O/LAY (N+WP)
44-065	1987	0.0	0.0	N/A	O/LAY (N+WP)
44-164	1990	0.0	0.0	N/A	P.W.P.
38S-001	1990	0.0	0.0	N/A	O/LAY (N)
38S-002	1989	0.0	0.0	N/A	P.W.P.

SITE	REHAB_YR	RPOTENT1	RPOTENT2	REH_DEL	METHOD_REH
38S-258	1988	17.8	52.0	Only half the deck was surveyed. 35m found to be delam. 60% of these areas were in locations with high corr. potent. Corr. potent. are 1/2 of half of the deck area only.	N/A
41S-074	0	0.0	0.0	N/A	
45E-003	0	0.0	0.0	N/A	
48C-008	1988	26.9	76.1	Measurements for half of deck only, 65m/242=26.9, 3% > -0.2 V cse. 14m/242 with delam., 80% delam. in area of high half cell readings.	O/LAY(N+W)
48C-011	0	0.0	0.0	N/A	
48C-023	0	0.0	0.0	N/A	
48C-030	0	0.0	0.0	N/A	
48C-098	0	0.0	0.0	N/A	
48C-100	0	0.0	0.0	N/A	
48C-102	0	0.0	0.0	N/A	
48E-008	1988	0.0	10.0	40m = 10% of delam. measured and removed. Based on south side of deck only, in condition survey no active corrosion in this half and only 2/3 of .21-.35 V cse readings.	O/LAY (N+W)
48E-027	1983	0.0	0.0	N/A	O/LAY (N+W)
48W-044	0	0.0	0.0	N/A	
05-050	1989	0.0	0.0	N/A	P.H.P.
05-186	1990	0.0	0.0	N/A	CP
06-059	0	0.0	0.0	N/A	
06-120	0	0.0	0.0	N/A	
12-058	0	0.0	0.0	N/A	
12-059	0	0.0	0.0	N/A	
12-060	0	0.0	0.0	N/A	
14-233	1988	0.0	0.0	N/A	O/LAY(L)
19-229	0	0.0	0.0	N/A	
19-230	0	0.0	0.0	N/A	
19-369	1989	0.0	0.0	N/A	N/A
19-373	1989	0.0	0.0	N/A	P.H.P.
19-374	1990	0.0	0.0	N/A	P.H.P.
23-122	1990	10.7	29.9	Delaminations <.2 = 51m =16.3% Delaminations 0.2 to 0.35 =14m =10.8% Delaminations >0.35 = 24m	

SITE	REHAB_YR	RPOTENT1	RPOTENT2	REH_DEL	METHOD_REH
				=7.7%, Total =34.8%	
30-208	1988	0.0	0.0	N/A	O/LAY(L+WP)
33-148	1989	0.0	0.0	N/A	O/LAY(N+WP)
33-149	1989	0.0	0.0	N/A	O/LAY(N+WP)
33-150 SBL	1989	0.0	0.0	N/A	O/LAY(L+WP)
33-151	1990	0.0	0.0	N/A	CP(O/LAY)
33-175	1990	0.0	0.0	N/A	CP(O/LAY)
33-176	1990	0.7	74.2	Delaminations <0.2 =12M =1.6% Delaminations 0.2 to 0.35 =54M =7.4% Delaminations >.35 =0.8M =.11%, Total =9.11%	P.N.P.
33-177	1990	0.0	0.0	Delaminations <0.2 =12M =2.4% Delaminations 0.2 to 0.35 =40M =8% Delaminations >0.35 =21M =4.2%, Total =14.6%	P.N.P.
35-005	1989	0.0	0.0	N/A	RD

SITE	REMARKS	DART
09-042	<p>Concrete cover min.=30, max.=75mm. In surv.1- 78% > 40mm, 22% 30-35mm. Air content = 6.7%, spacing factor and specific surface are outside acceptable parameters. P/c = 62,66.9,68.7/61,73.1,73.2 MPa. Chlorides, 10/.011//.016//.0130/.016//.008//.008.50/.014//.011//.009,70/.018//.011//.009,90/.013//.009//.009</p> <p>Asphalt thickness min.=70, max.=115, avg.=92mm. W/P is fibre reinforced emulsion, 2-6mm, fair bond. Soffit; surv.1 & 2- not inspected water level to high, in 1986, Ministry forces did survey, u/s good. Surface; surv.1- 8/11 cores slightly rusted rebar, samples dry. Surv.2- 3/12 cores with vetr/horz. cracking to depth of 20mm, t=185m. Concrete cover min.=60, max.=135mm. Air content = 3%, spacing factor and specific surface outside acceptable parameters. P/c = 62,77.7,82.7/59.8 MPa. Chlorides, 10/.141//.232,30/.095//.174, 50/.073//.136,70/.056//.097,90/.023//.053. Asphalt thickness min.=70, max.=130, avg.=95mm. Soffit; surv.1- many cracks with water and efflor.</p> <p>stains, slight scaling, girders rusted at deck interface. Surv.2- numerous leached cracks(225m, 80% trans.), spalls (11.1m) and delam.(3.4m) at joints, wet areas(4.8m). Surface; surv.1- all 16 cores with deter, 14/15 with rebar slightly rusted, 1/16 m. scaled, 5/16 slight scaled, 25-55mm 4/16, disintegrate to agg. 2/16.</p>	N/A
09-044		N/A

SITE	REMARKS	DART
10-160	<p>Slight scaling 2/3 samples, 1/3 with severe scaling. Surv. 2- 17/22 deter., 11/22 top portion disintegrated</p> <p>20-100mm all but 1 of these cores also with multiple delam.</p> <p>from 20-135mm below distinct. portion. Additional 6 cores</p> <p>with multiple delam. only 20-135mm. 1/22 m. scaling. 3/4</p> <p>samples disintegrated to 30-50mm, 1/4 delam. 4.5% <-0.55V CSE, 34% <-0.45V CSE.</p> <p>Structure built in 1936. Widened in 1959.</p> <p>Concrete cover for the widened deck, min.=25, max.=135. 24% cores cover<240mm. P/c >65 Mpa original deck, >45 Mpa widened deck.</p> <p>org.=47.1, 52.5/40.3, 47.2, 53.4, new=86.4, 95.2/67.8, 78.6, 83.3</p> <p>Chlorides, original deck; 10/.114/.039/.116//.041//.056, 30/.096/.036/.106//.034//.032.</p> <p>50/.064/.032/.1//.027//.018, 70/.05/.031/.087//.019//.012,</p> <p>90/.041/.021/.054//.014//.008. First core tested to 210mm</p> <p>depth, 110/.053, 130/.05, 150/.068, 170/.09, 190/.102, 210/.102</p> <p>2. Widened deck;</p> <p>10/.204/.179, 30/.173/.115, 50/.135/.052, 70/.122/.034, 90/.097/.027.</p> <p>Asphalt thickness, original = 140-240mm, widened = 40-145mm. W/P is a mastic membrane, first waterproofed in 1969 with a rubberized mastic.</p> <p>Soffit, numerous cracks (308m) all leaching, spalling on u/s (57.8m), conc. beams and pier caps had many areas of ERB and spalling. Most of this deter. is on original structure. Heavy spalling on</p>	N/A

SITE	REMARKS	DART
18-104	<p>arch beams with corroded ERB, heavy spalling on piers footings with very wide vert. cracks. Surface, some delam. and patches on upper section of cores and samples, mainly on original struct., disintegration adjacent to expansion jts. and long. constr. jts.</p> <p>Concrete cover min.=15, max.=95mm. P/c = 61.3, 64.5, 75.9, 77.4, 74.8, 75.4, 80.1, 82.2, 86 MPa.</p> <p>Chlorides, 10/.182/.108/.173/.091/.180/.163/.114, 30/.142/.097/.138/.074/.138/.133/.136, 50/.109/.082/.097/.055/.082/.108/.090, 70/.071/.070/.077/.048/.048/.071/.085, 90/.043/.059/.072/.049/.042/.048/.062, 1 core in surv.1 continued to 250mm, 110/.041, 130/.044, 150/.045, 170/.073, 190/.135, 210/.228, 230/.306, 250/.364.</p> <p>soffit; surv.1- numerous long. (95m) and trans. (96m) cr. almost all with leached deposits. Considerable amount of spalls (62.7m) and delam. (10m). Five full depth cores show chloride penetr. to bot. mat of steel, and delam. to this level. Deter. usually near or under curbs and sidewalks. Wet areas = 4.8m.</p> <p>Surv.2- long. (252.6m) and trans. (105.8m) cr. growth, numerous rust stains, spalling (84.2m) and delamination (39.1m) growth with bottom mat of rebar actively corroding. Wet areas = 41m. Majority of deter. is at or near u/s sidewalks and curbs.</p> <p>Surface; surv.1- 99 cores, extensive delaminations and disintegration. 1 core deter. throughout the depth of the deck slab. Several rebar found in cores to be corroding. 7/20 samples wet. 2.2% < 0.45 v CSE. Surv.2- same as survey one, evidence of freeze-thaw deterioration with</p>	N/A

SITE	REMARKS	DART
18-191	<p>horizontal fractures (cracking). 4.8% < -0.45 V CSF. Concrete cover min. = 20, max. = 70mm. 69% cover 35-50mm, 28% > 50mm. Air content = 5%, spacing factor and specific surface outside acceptable parameters, 21.8 and 0.23. F'c = 40.6, 45.7 MPa. Chlorides, 10/.373/.116, 30/.194/.106, 50/.088/.042, 70/.029/.024, 90/.022/.020. Soffit; good Surface; Deck spalls patched with set-45, debonded in areas. 21 cores with rebar, 9/21 were rusted or corroding. 2.4% < -0.45V CSF. Concrete cover min. = 20, max. = 110mm, 17.9% deck area cover < 40mm. Air content = 3.3/7.1%, surv. 1-marginal, s.s. = 23.9, s.f. = 25 f'c = 67.2, 71.8, 74.4, 74.0/50.9, 58.5 MPa. Chlorides, 10/.604/.465, 30/.16/.206, .170, 50/.061/.075, .1.70/.042/.043, .043, 90/.054/.04, .043. Soffit; surv. 1- no cracks or water penetration surv. 2- numerous long. cracks (210m), especially at end spans. West span 2 areas map cracking (6.25m). Some ERB at spalls (0.1m). Surface; surv. 1- no medium or wide cracks. surv. 2- spalls with ERB and large areas for each spall. Deterioration mainly in N. half of structure. 4/5 cores with rebar, rebar corroding, no surface cracking recorded. 4% < -0.45V CSF.</p>	N/A
18-192		N/A
21-074	<p>Concrete cover min. = 43, max. = 73, in surv. 2 estimated cover less than 50mm over 66% of area. F'c = 36.36.8/35.4. Chloride depths, 10/0.170//0.110, 30/0.08//0.136, 50/0.055//0.116,</p>	N/A

DART

REMARKS

SITE

70/0.06//0.078,90/0.02//0.043.
Asphalt thickness min.=50, max.=183mm, avg.=143mm.
Asphalt in poor condition, many unsealed cracks in both surveys, poor bond to concrete, few potholes.
Soffit; surv.1- 238m of cracks, 12% have water penetration in form of staining and efflor. with stalactite formations. 1.2m of spalling, two with ERB, 2 long. c.j. leaking. Surv.2- 27.6% waterstained, 3.2m of spalls, HC delaminations and extensive cracking.(7.9m scaling, 1.9m patches, 2.5m delam.) Facia of deck has extensive random cracking with localized spalling with ERB, scaling and waterstaining both surveys.
Surface; surv.1- m-s scaling, loss up to 20mm of top surface.
Surv.2- Same as surv.1 plus 1/3 core delam. up to 160mm deep, white precipitate around agg. in all cores. Cores exhibit alkali agg. reaction.
Half-cells <-0.45VCSZ, surv.1=0, surv.2=62%.

N/A

21-159

Concrete cover min.=2, max.=111mm.
Air content = 6.4/8.8%, f'c = 29.6,55.3/44.5,48.9,49.4 MPa.
Chlorides
10/.021//.05//.023,30/.011//.089//.005,
50/.006//.026//.005,70/.005//.012//.004,90/.004//.005//.006.
Asphalt thickness min.=59, max.=90, avg.=70mm.
Bond to concrete is poor.
Soffit; surv.1- good. Surv.2- minor cracking(32.6m), localized patches(1.9m),trans. cr. and wet stains u/s curbs, 1. scaling(3m), wet stains(32.4m, includes girders). Wide vert. crack in diaphragms at pier locations.
Surface; surv.1- good. surv.2- 7 samples- rust stain surface and deter. of top layer 3/7 with several corroded rebar and little cover, 2/7 with

SITE	REMARKS	DART
21-160	<p>surface deter., 2/7 were good. 10 cores- 1/10 deter. at top, 1/10 delam. at rebar, 1/10 corroded rebar.</p> <p>Concrete cover min.=21, max.=56mm. 71% concrete cover reading <30mm. Air content = 6.6%, f'c = /41.5, 45.8, 56.6 MPa. Chlorides, 10//.005//.007, 30//.006//.006, 50//.004//.005. Asphalt thickness min.=70, max.=95, avg.=81mm. Soffit; surv.2- local patches(0.1m), waterstains(66.2m), spalls(2.4m) and scaling(1.1m). Curb u/s with trans. cracks (23.5) and waterstains. Surface; surv.2- deter. along curbs and expansion joints, 2/10 cores with det top 8mm, vertical cracking and delam. 11-105mm, 2/10 rebar 2/10. Samples, all dry, 2/6 deter. to 5mm, one with rust stained surface, 2/6 rust stained, 1/6 with delam. t-180mm. curbs extensively cracked.</p>	N/A
21-164 21-247	<p>N/A</p> <p>Concrete cover min.=15, max.=53, avg.=29mm. 75% of deck avg. cover < 50mm. f'c = 36.6, 40.5, 40.9, 41.1 MPa. Chlorides, 10//.115/.184/.284/.132//.106, 30//.065/.102/.173/.107/.096, 50//.083/.031/.116/.08 5//.058, 70//.0.9/.028/.059/.042//.030, 90/.023/.030/.028/.02 6//.025</p> <p>Values corrected for background chl. in depth1 and 2 cores. Asphalt thickness min.=65, max.=130, avg.=99mm. Soffit; surv.1- extensive random cr. (3669m) except near piers,</p>	N/A N/A

SITE	REPAIRS	DART
21-160	<p>Concrete cover min.=21, max.=56mm. 71% concrete cover reading <30mm. Air content = 6.6%, f'c = /41.5,45.8,56.6 MPa. Chlorides, 10//.005//.007,30//.006//.005, 50//.004//.005. Asphalt thickness min.=70, max.=95, avg.=81mm. Soffit; surv.2- local patches(0.1m), waterstains(68.2m), spalls(2.4m) and scaling(1.1m). Curb u/s with trans. cracks (23.5) and waterstains. Surface; surv.2- deter. along curbs and expansion joints, 2/10 cores with det top 8mm, vertical cracking and delam. 31-105mm, minorly corroding rebar 2/10. Samples, all dry, 2/6 deter. to 5mm, one with rust stained surface, 2/6 rust stained, 1/6 with delam. t-180mm. Curbs extensively cracked.</p>	N/A
21-164	<p>Concrete cover min.=12, max. =62mm. 47% of deck concrete cover <25mm. Air content =4.5%, f'c = 27.4,34.1,39.9/42.4,45.2,50.6 MPa. Chlorides, 10/.006//.026//.202,30/.003//.005//.174, 50/.003//.006//.192,70/.003//.005//.144,90/.003//. 007//.088. Asphalt thickness min.=75, max.=148, avg.=110mm. 380m of sealed cracks, 551m unsealed cracks. W/P asphalt emulsion, 2m, poor condition. Soffit; surv.1- four trans. ver cr. north of s. pier. Surv.2- 174m cracks, 110m leached, 50m wet stains with local spalling and delam. mainly on S. side. Surface; Surv.1- good. Surv.2- delam. and deter. to max. depth of 54mm span between piers 2 and 3 and adjacent to abutment expansion joints. Corroded ERB, deter. to 20mm at 1 sample and 4/9 cores with rebar show corrosion of rebar.</p>	N/A

SITE	REMARKS	DART
21-247	<p>8.9% < -0.45 V cse.</p> <p>Concrete cover min. = 15, max. = 53, avg. = 29mm. 75% of deck avg. cover < 50mm. F'c = 36.6, 40.5, 40.9, 41.1 MPa. Chlorides, 10/.115/.184/.284/.132//.106, 30/.065/.102/.173/.107//.096, 50/.083/.031/.116/.08 3//.058, 70/.019/.028/.059/.042//.030, 90/.023/.030/.028/.02 6//.025. Values corrected for background chl. in depth and 2 coils. Asphalt thickness min. = 65, max. = 130, avg. = 99mm. Soffit; surv. 1 - extensive random cr. (3668m) except near piers, extensive damp areas (11.4% = 53.8m), local spalling, H.C., scaling and patches (2.7% total). Surv. 2 - wet areas expanded to 72.8m. Surface; surv. 1 - 13/20 cores top portion deter. or scaled, 2/20 top portion wet, 4/20 diam 10-100mm. 5/12 samples damp and deter. 3-65mm, 3/12 l. scaling. *24.3% < -0.45 V CSE*. Surv. 2 - 3/4 cores in areas of high half-cell, deter. to 10mm depth, 2/4 samples l. scaling, 1/4 deter. to 25mm and damp with corroded ERB. *46.8% < -0.45 V CSE*.</p>	N/A

SITE	REMARKS	DART
22-002	<p>extensive damp areas(11.4% = 53.8m), local spalling, H.C., scaling and patches(2.7% total). Surv.2- wet areas expanded to 72.8m. Surface; surv.1- 13/20 cores top portion deter. or scaled, 2/20 top portion wet, 4/20 delam 10-100mm. 5/12 samples damp and deter. 5-65mm, 3/12 1. scaling. Surv.2- 3/4 cores in areas of high half-cell, deter. to 10mm depth, 2/4 samples 1. scaling, 1/4 deter. to 25mm and damp with corroded ERB. "46.8% <-0.45 V CSE". Concrete cover min.=40, max.=90mm. F'c = 50.5,55.3,58.2/50.6,51.6 MPa. Chlorides, 10/.217,30/.176,50/.148,70/.129,90/.071. Chlorides for survey one only. Asphalt thickness min.=100, max.=160, avg.=132mm. Poor bond between asphalt and concrete surface. Soffit; surv.1- few rust stains with spalls and ERB, few long. cracks with leach deposits. S. end fascia heavy spalling with ERB. Surv.2- 33m of cracks, 37.6% are efflor. and stained. 2.7m spalled. Surface; surv.1-6/16 cores deteriorated from 5-150mm deep. 1/16 cores scaled.2/3 samples disintegrated, the 150mm revealed rusted rebar, both samples wet. 1/3 samples m. scaled. Surv.2- 1/3 cores disintegrated to 75mm, 1/2 samples 70% delam. to 25mm with scaling over entire area up to 10mm deep. 3.5% < -0.55V CSE, 25.5% < -0.45V CSE.</p>	N/A
22-004	<p>Concrete cover min.=40, max.=60mm. F'c = 46.3,51.9,55.5/19.7,28MPa, results from</p>	N/A

SITE	REMARKS	DART
22-005	<p>survey 2 were not used, premature shearin of samples occurred, may reduce f'c. Chloride dpth, 10/0.086,30/0.081,50/0.084,70/0.012,90/0.002. Asphalt thickness min.=80, max.=145, avg.=102mm. Bond to conc. was poor, many unsealed cracks, poor. Soffit/surv.1- HC, trans. and long. cracks with numerous rust stains, corroded ERB, spalls scaled areas within 2m of outside curb.Surv.2- poor, 109.4m cracks, 33% with water penetration/staining and efflor., 128.2m of rusted ERB, 41.8% of u/s wet, 1.7% of u/s spalled. Surface; surv.1- 5/14 cores were rebar encountered, rebar was slightly rusted, 3/3 asp. samples were damp, 1/3 asp. samples and 1 core, surface disintegrated to 25mm. Surv.2- 2/2 asp. samples wet surface plus delam. over 30-40% of area. A-2, delam. 46mm deep, A-1, 5-10mm deep.Full depth det. at drains. Steel members have undergone some corrosion in a few areas. Half-cells <-0.45VCSE, surv.1=0, surv.2=46.6t.</p> <p>Concrete cover min.=10, max.=90mm, avg. was estimated from contours. 22% area cover <30mm, 43% area 30mm<cover<50mm, 45% area >50mm cover. Surv.1 only. Air content = 3.8,5.1,5.2,6.0,8.1,8.1,8.6,8.9,9.1t.Surv.1 only. F'c = 36.2,39.5,40.3,42.7,45.5,46.0,46.5, 47.5,56.0,56.7,63.2/52.4,59.8 MPa. Chlorides, 10/.18/.24/.089/.39/.3/.062/.36/.22/.39/.33/.37, 30/.16/.081/.041/.23/.23/.12/.15/.13/.16/.21/.10, 50/.097/.027/.034/.064/.043/.017/.16/.041/.065/.11 /.03 70/.057/.02/.031/.035/.027/.023/.11/.032/.036/.064</p>	N/A

SITE	REMARKS	DART
22-113	<p>/.024, 90/.036/.031/.021/.032/.057/.041/.12/.019/.019/.04 9/.031. Soffit; surv.1- long, cracks coincident with sonovoid tubes, some with leach stains. Surv.2- long, cr.= 1700m, random cr.=45m, very few leaching. Wet areas = 67m = 1.6%, spalls = 5m. Surface; surv.1- long, cracks (592m-m., 275m-v.) coincident with sonovoid tubes. Light to moderate scaling over 100% of deck area, rust stains with ERB <1m. 36 cores, 17 cores with rebar, 7 with corrosion. Surv.2- trans. Cr.= 75m, long, cr. = 4025m, random/diagonal = 137m. 32% of the cracks are wide. Extensive surface wear down to the coarse aggregate. 0.7% < 0.45 V CSE.</p> <p>Concrete cover min.=32, max=70mm. 35% of deck area N/A cover between, 35-50mm, 62% cover > 50mm. Air content = 6.3%, spacing factor and specific surface outside acceptable parameters. F'c = 41.9, 43.7, 50.7/38.9MPa. Chloride, 10/0.418//0.276, 30/0.22//0.13, 50/0.078//0.089, 70/0.009//0.066, 90/0.005//0.021%. Soffit; has a few trans. and long, cracks - some efflor. and rust staining at cracks. No signif. increase in 1988. Surface; numerous long, and diagonal cracking (28m), surv.2 no real change except delam. 10-40mm in 2/4 cores and core over patch patch not bonded at 80mm depth. t=210mm. Half-cell <-0.45V CSE, surv.1 = 4.1%, surv.2 = 6.6%.</p>	
22-149	STRUCTURE WAS WIDENED TO THE WEST IN 1957 "SURVEY-1"	N/A

DART

REMARKS

SITE

Concrete cover min.=58, max.=129mm.
F'c=31.9, 43.4MPa.
Chloride depth
10/0.058/0.03, 30/0.024/0.025, 50/0.006/0.018.
Asphalt thickness min.=112, max.=245, avg.=186mm.
W/p bitumen emulsion material, poor bond.
Soffit, long. jt. is leaching, some areas of
calcium deposits. 4% spalled, 4% with rusted ERB.
Surface is m-s scaled at all samples. Extensive
delam. at east deck, 5-35mm. Half-cells higher at
east deck. 15%<-0.45VCSE.
Deck drains plugged and det.

"SURVEY-2"

Concrete cover min.=60, max.=80mm.
F'c=33.1, 36.2MPa.
Asphalt thickness min.=140, max.=250, avg.=190mm.
Numerous unsealed cracks, f-p, poor bond, NO W/P.
Soffit, most det. on east side, 1.8% spalls, 1.8%
HC, 1.8% patch, 39m of cracks with leaching.
Surface is wet in all samples. Scaling to 30mm
deep 3/4 cores all samples, one severely corroded
rebar in sample location at centre of highway.
Half-cells, 5.1%<-0.45VCSE.

"SURVEY-3"

Concrete cover min.=21, max.=63mm, estimated cover
less than 50mm for 50% of deck.
F'c=35MPa for west deck. East deck to badly
corroded to test.
Chloride
depth, 10, 30/EO.092, 50/EO.125/40.048, 70/EO.083/0.07
90/EO.076/40.069.
Asphalt thickness min.=156, max.=253, avg.=193mm.
Poor bond, NO W/P, many unsealed cracks.
Soffit, East side many ERB, rusted, damp, some
erb patched with mastic material. West side large

SITE	REMARKS	DART
22-334	<p>area of scaling. Wet=2%, scaling=6%, patch=1.3%, delam.=2.5%, 46m of leached cracks. Surface, east side is wet and granulated to a depth of 76mm, extensive delam. to 76mm, perhaps alkali agg. reaction. 4/5 cores, 2/3 asp. samples. West side, fair damp and granulated to 35mm in 1 asp. sample delam. noted in one core. Half-cells; 0.21-0.35 = 41.3% < 0.35 = 58.7% < 0.45 = 23.8%</p> <p>Concrete cover min= 35, max= 90mm Air content =3.4%, s.f. and s.s. outside limits, surv.1 only. P'C =43.8,53,54/33.2,33.7 MPa.</p> <p>Chlorides, 10/204,30/.152,50/.095,70/.047,90/.032. Asphalt thickness min= 110, max= 135, avg.= 120mm Bond to concrete poor. Soffit; surv.1- some leaking at long. constr. jt. with leached deposits, few long. cr. and rust spots. surv.2- 30m long. cr., 9.5 trans. cr., 5.9m rand.; 24% with efflor., wet spots 18.8m, spalls 1.1m, 6.0m ERB. Long. const. jt. leaking. Surface; surv.1-good. surv.2- 1/1 sample, surface wet.</p> <p>Concrete cover min.=30, max.=70. Surv.1 only. Air 2.5,7.1/5.5%, specific surface and spacing factor outside acceptable parameters. P'C = 47.5,50.1MPa. Chloride depths 10/0.467/0.523//0.241//0.379, 30/0.263/0.391//0.143//0.181,50/0.066/0.105//0.063//0.039, 70/0.061/0.027//0.011//0.027,90/0.02/0.021//0.02//0.025.</p>	N/A
24-106		N/A

SITE	REMARKS	DART
24-211	<p>Soffit in both surveys large wet area in center span coinciding with the area showing signs of surface deter., at the large patched area in surv. 2 where half-cells are high. Surface is trans. tined finished which is traffic worn, t=200mm. Half-cells <0.45VCS2 surv.1=0.6%, surv.2=1.8%. Alkali agg. reaction is suspected. 6/12 cores are del. in surv.2. SURVEY 3 DONE IN 1989. Concrete cover min.=35, max.=90mm. Air content= surv.1-8.5%, surv.3- 5.4%, in both cases s.f. just outside limits, 23.1 and 23.8. P/C = surv.1- 34.1,35.1,39.3,41.2, surv.2- 44.4 MPa. Chlorides, 10/.064/.196//.153//.039//.011, 30/.058/.102//.143//.027//.008, 50/.060/.031//.131//.016//.009, 70/.060/.011//.103//.012//.005, 90/.058/.007//.082//.017//.005. Asphalt thickness min.=65, max.=120, avg.=85mm. W/P surv.1- none, surv.2 - mastic membrane, t=5mm, surv.3- hot applied rubberized asphalt, t=5-8mm, bond fair-good. Soffit; surv.1- limited trans. cr., rust from rebar chairs. Surv.2- same as one, addition of delam. at north abutment on centre beam and beam immediately to the west. Surv.3- not conducted. Surface; surv.1- 28 cores, 19 with rebar, 18 of these rebar were slightly rusted. 1/28 broke horiz. at rebar. Surv.2- 16 cores, 1 with severely rusted rebar, 1 with vert. cr. to 170mm. 5 samples, 1 with surface scaling and wet - at curb. Surv.3- 6 samples, 1 delam., 1 with rust staining</p>	N/A

SITE	REMARKS	DART
24-214	<p>on surface. Concrete cover min.=40, max.=100mm. Air entrainment was marginal, poor air void structure. F'c = 41,41.3,42.9,48.2,50.3,52MPa. Chloride depths, 10/0.526/0.159//0.165,30/0.326/0.201//0.117,50/0.19/0.143//0.072,70/0.086/0.081//0.02,90/0.02/0.032//0.013%.</p> <p>Soffit, long. cracks with leached deposits. Few trans. cracks mainly on E. side. Surv.2, same with rust staining at some of long. crack locations. Surface; surv.1- some w.long. cracks, delam.=15.2m, spalls=0.7m, 3/17 cores delam., rebar slightly rusted in most cores. Surv.2- 4.1½ delam, 4.4½ spalls patched with asphalt.Delam. depth = 25mm, not consistent with delam. due to rebar corrosion. Suspect alkali agg. reaction.(agg. sheared through plane of delam.)Half-cells <-0.45VCSE, surv.1=10½, surv.2=44.7½ - 7.3½<-0.55VCSE. Concrete cover min.= 20, max.=96mm. Air content = 4.2½, spacing factor and specific surface outside acceptable limits. F'c = 49.8,57.5/30.7,40.8 MPa. Chlorides, 10/.1/.117,50/.088/.065,50/.035/.035,70/.023/.019.</p>	N/A
26-060	<p>Asphalt thickness min.=50, max.=100, avg.=78mm. W/P is an asphaltic material, 4mm, f-p bond. Soffit; surv.1- few hairline cracks with some efflor. and leaching, mainly on west side. Surv.2- 61m of cracks, mostly at west side, this area is wet, efflor. at a few cracks. Coping u/s has minor spalls and rust stains. Surface; surv.1- 1/6 cores delam. with rust stains to 35mm, 3/3 samples scaled. Surv.2- 1/3 cores with horiz. cracks at 30mm, rusting of iron rich</p>	N/A

SITE	REMARKS	DART
26-061	agg. at this pt. 1/1 samples at curb 50% vet. Concrete cover min. = 20, max. = 80mm. Air content = 6.2, 7.9%, spacing factor and specific surface outside acceptable parameters. F'c = 32.3, 36.41, 3.42, 9.47, 8.47, 8.47, 8.51, 1.1, 56.3, 36.4, 36.9, 44.8 MPa. Chlorides, 10/.265/.198/.088, 30/.222/.145/.065, 50/.074/.085/.03, 121/.025/.017, 90/.078/.018/.015. Asphalt thickness min. = 50, max. = 85, avg. = 65mm. W/P is an asphaltic material, 5mm, bond g-p. Soffit; surv. 1- 126m not accessible for inspection because over river. Numerous cracks with leached deposits, mainly trans. and at sides of the bridge. Some H.C., spalling and ERB. Surv. 2- 1230m of cracks, 30% are efflor. and stained, spalls (9m), wet areas (123.3m), H.C. (8.7m). Surface; surv. 1- 44 cores, 38 with rebar, slight rust in 14/38 cores, 2/44 horiz. cracked, delam. 2-20mm 2/44 cores, 12 samples, sl. scaled 1/12, h. scaled (15mm) 2/12, damp 1/12, sample adjacent to expansion jt. deteriorated, 50% corrosion of exposed rebar and damp. Surv. 2- 1/2 samples wet, h. scaled to 15mm entire area, rust stain on surface 1/2 samples at drain. 0.2% <-0.55V CSE, 3.4% <-0.45V CSE. Concrete cover; min = 15, max = 55 Air content; 4.1, s.s. = 7.6, s.f. = .58 F'c = 40, 60/39.4, 32.1 Chloride; 10/.2268/.0986, 30/.1849/.0776, 50/.1308/.0325 NB chloride samples taken only to 50mm, chlorides for surv. 1 only, Asphalt thickness; min = 55, max = 105, avg = 82 W/P is asphalt emulsion, t-2-1mm.	N/A
26-081		N/A

SITE	REMARKS	DART
32-065	<p>soffit; surv.1-large wet areas and rust stains in north and south spans along centreline. surv.2-trans cr. =255, long. cr. =25, other =10, wet spots 69, spalls 1.5, honeycombing =8.3</p> <p>scaling =5.1.</p> <p>surface; surv.1-fair to crumbling, 6 cores, 4/6 with rebar</p> <p>in good cond. surv.2- 4 cores, 1/4 disint. 15mm, 2 samples, both wet with scaling to 20mm depth, 1 with delam. over 30% of area.</p> <p>Concrete cover min.= 100, max.=140mm., only have four readings, to deep to measure in asphalt samples.</p> <p>P/C = 50.1, 59.1, 80.9 MPa, survey 1 only.</p> <p>Chlorides, 10/.228//.098//.30/.224//.088//.146, 50/.207//.063//.114, 70/.21//.046//.086, 90/.182//.034//.066.</p> <p>Asphalt thickness min.=160, max.=365, avg.=200mm. Soffit; surv.1- good, trans. and long. constr. jt. is leaking and efflor. stained. Surv.2- few long. and trans. leaching cracks primarily under sidewalk. Long. and trans. construction jts. are leaking and stalactites have developed.</p> <p>Surface; surv.1- 10 cores, 4/10 with multiple hairline fractures from 20-150mm, 2/10 disint. top 10-30mm, 3/10 with top 10-90mm disint. followed by hairline fractures up to 120mm. 3/3 samples damp with surface disint. to 20-30mm deep. 10.7% <-0.15 V CSE. Surv.2- 8 cores all with surface deterioration from 10-50mm, 3 with horizontal fractures up to an additional 90mm and weak cement paste noted in 4/8. 3 samples, 1/3 damp with 100 surface deter., 1/3 with 20mm deter. Deter. contributed to freeze-thaw. 17.5% <-0.45V CSE.</p>	N/A
34-033	<p>Concrete cover min.= 100, max.=140mm., only have</p>	N/A

SITE REMARKS DART

four readings, to deep to measure in asphalt samples.
f'c = 50.1, 59.1, 80.9 MPa, survey 1 only.
Chlorides, 10/.228//.098//.30/.224//.088//.146,
50/.207//.063//.114, 70/.21//.046//.086, 90/.182//.034//.066.
Asphalt thickness min.=160, max.=365, avg.=200mm.
Soffit, surv.1- good, trans. and long. constr. jt. is leaking and efflor. stained. Surv.2- few long. and trans. leaching cracks primarily under sidewalk. Long. and trans. construction jts. are leaking and stalactites have developed.
Surface; surv.1- 10 cores, 4/10 with multiple hairline fractures from 20-150mm, 2/10 disint. top 10-30mm, 3/10 with top 20-90mm disint. followed by hairline fractures up to 120mm. 3/3 samples damp with surface disint. to 20-30mm deep. 10.7% < -0.45 V CSE. Surv.2- 8 cores all with surface deterioration from 10-50mm, 3 with horizontal fractures up to an additional 90mm and weak cement paste noted in 4/8. 3 samples, 1/3 damp with 100 surface deter., 1/3 with 20mm deter. Deter. contributed to freeze-thaw. 17.5% < -0.45V CSE.

34-193A
34-210

N/A
N/A

Concrete cover =45, min =0, max=60mm, cover less than 20= 7.4 -1.1%, cover 20 to 50 =369.9 -4.1%, greater than 50 =291.7 -43.6%
Air content =6.5%, spacing factor =.15 outside acceptable limits.
f'c = 50.5, 51.6, 52.7 MPa.
Chlorides, 10/.211//.414//.47//.254, 30/.115/.184//.257//.173, 50/.042/.064//.07//.054, 70/.039/.051//.028//.031, 90/.046/.039//.031//.036
Soffit; surv.1 -trans. cr.=6.1 with leach deposits. Surv.2 -trans. cr.=2.2m, long. cr. =3.3m, other =4.1m few spalls =.21m and some exposed

SITE	REMARKS	DART
36-034	<p>rebar. Surface, surv.1 -trans. cr. =6.4m, long. cr. =1.4m, diag. cr. =2.1m, 2.7% <-0.45 V cse. Surv.2 = trans cr. =7.3m, rand. cr. =2.6m, 8.5% <-0.45 V cse. Concrete cover min =45, max =95mm. Air content= 10.1, 3.4%, s.s.=22.1, s.f.=13.3 F'c = 48, 47.9, 40.8 MPa, surv.1 only. Chlorides, 10/.049/.039//.041//.08, 30/.044/.038//.038//.071, 50/.041/.05//.038//.060, 70/.037/.036//.04//.047, 90/.039/.043//.03//.037. Asphalt thickness min =75, max =115, avg =101mm. W/P membrane, 1mm mastic poor-good bond with concrete Soffit/surv.1-general good condition with few wide cracks, surv.2-general good condition with few leached transverse cracks. Surface/ surv.1 -generally good, surv.2 -quality of concrete good, one core with full depth long. crack.</p>	N/A
36-096	<p>Concrete cover min.= 25, max.= 95mm, 87% area cover >50mm. Air content = 4.3%, s.s.=22.1 and s.f.=0.24 just outside acceptable parameters. F'c = 68.4, 69.9 MPa, surv.1 only. Chlorides, 10/.245/.082//.323//.120, 30/.106/.025//.123//.019, 50/.025/.018//.018//.013, 70/.019/.015//.014//.013, 90/.015/.016//.013//.013. Soffit/ surv.1-extensive long. cracking (1083m), some with leach stains (22.5m), run parallel to</p>	N/A

SITE	REMARKS	DART
37-230 EBL	Concrete cover min. = 20, max. = 100mm, 5% of deck area cover < 40mm, s.f. = 20.7, s.s. = .24, just outside limits, assume marginal air entrapment. Cover, air and chlorides surv. 1 only. P/C = 65.6, 69.2, 72/48.5, 63.6 MPa. Chlorides 10/.357, 30/.155, 50/.047, 70/.026, 90/.022. Soffit; surv. 1 - several long. and diagonal med. width cr. some leaching. Surv. 2 - 4.1m trans. cr., 141.7m long. cr., 212.5m random cr., 23.5m vet areas and 0.3m spalled. Surface; surv. 1 - many wide and a few medium cracks, few diagonal at west end. 2.5% < 0.45 V CSE. Surv. 2 - 4.3m narrow trans. cr., 603m long. cr. with 19.2% med. in width, 45.9m diagonal cr. with 7.8% med. width and 9.4% wide in width. 10.9m = 0.5% med. scaled. 10.5% < 0.45 V CSE, 2.2% < 0.55 V CSE.	N/A
37-230 HBL	Concrete cover min. = 25, max. = 100mm, 14.8% of area cover < 40mm. Air content = 7.5%, s.f. = 21.8, just outside acceptable limit. Cover, air and chlorides surv. 1 only. P/C = 54.6, 59.1, 62.2/43.7, 48.5 MPa. Chlorides 10/.403, 30/.281, 50/.161, 70/.074, 90/.042. Soffit; surv. 1 - several long. and diagonal med. width cr.; some leaching. Surv. 2 - 19.6m trans. cr., 52m long. cr., 209m random cr., 18.2% of all cracks leaching. Wet areas = 54.1m, spalls = 1.7m. Surface; surv. 1 - many wide and a few med. long. cr., diagonal cr. at west end of deck. Surv. 2 - 6.7m of med. scaling, 922m long. cr., 457 are narrow and 465 are med. 52m diagonal cr., 13	N/A

SITE	REMARKS	DART
37-311 #5	<p>are med. 10.5% < -0.45 V CSE, 2.3% < -0.55 V CSE.</p> <p>Concrete cover: min = 25, max = 85mm Air content: 4.45, 5.77%, 5.8 = 29.3, 6.1. = .165 F'c = 65.5, 66.7, 71.1, 71.9, 72.9, 78 Chloride 10/.027/.037/.03/.031/.029/.30/.03/.029/.026/.02/.0 18. 50/.024/.024/.022/.017/.02, 70/.024/.026/.025/.02/. 019, 90/.024/.026/.026/.025/.026 Asphalt thickness: min=50, max =95, avg =70.9mm Numerous long. cr. width =3-40mm, short diagonal and trans. cr. also present, did not penetrate full depth of asphalt. Fair to poor bond between layers of asphalt soffit; numerous narrow long. cr. with leaching, cr. also appearing at bot. of sonovoid tubes. Surface; 11 cores with rebar, 10/11 slightly rusted. Cond. of concrete sound-good.</p>	N/A
37-311 #8	<p>Concrete cover min.= 40, max.= 75mm, avg. on 4 readings only. Air content = 5.2, 5.5%. F'c = 56.5, 63.3, 64.3, 65.5 MPa. Chlorides, 10/.019/.018, 30/.019/.02, 50/.017/.02, 70/.022/.023, 90/.02/.022. Asphalt thickness min.= 95, max.=120, avg.=110mm. W/P good bond good condition, not stated what type it was. Total length of cr. on asphalt deck surface =241m. Soffit; surv. i-.220m narrow long. cr. mainly under sonotubes; leached stained, 0.5m of conc. spalled from soffit surface. Surface; surv. i- 8/9 cores with rebar slightly</p>	N/A

SITE	REMARKS	DART
37-322	<p>rusted.</p> <p>Concrete cover: min =15, max =55 Air content: 4.1, s.s. =7.6, s.f. =.58 F/c =40,60/39.4,32.1 Chloride; 10/.2268/.0986,30/.1849/.0776,50/.2308/.0325 NB chloride samples taken only to 50mm, chlorides for surv.1 only. Asphalt thickness; min =55, max =105, avg =82 W/P is asphalt emulsion, t=2-4mm. Soffit; surv.1-large wet areas and rust stains in north and south spans along centreline. surv.2-trans cr. =255, long. cr. =25, other =30, wet spots 69, spalls 1.5, honeycombing =8.3 scaling =5.1. Surface; surv.1-fair to crumbling, 6 cores, 4/6 with rebar in good cond. surv.2- 4 cores, 1/4 disint. 15mm, 2 samples, both wet with scaling to 20mm depth, 1 with delam. over 30% of area.</p>	N/A
37-324 #2	<p>Concrete cover min.=10, max.=90mm, avg. was estimated from contours. 22% area cover <30mm, 43% area 30mm<cover<50mm, 45% area >50mm cover. Surv.1 only. Air content = 3.8, 5.1, 5.2, 6.0, 8.1, 8.1, 8.6, 8.9, 9.1%. Surv.1 only. F/c = 36.2, 39.5, 40.3, 42.7, 45.5, 46.0, 46.5, 47.5, 56.0, 56.7, 63.2/52.4, 59.8 MPa. Chlorides 10/.18/.24/.089/.39/.3/.062/.36/.22/.39/.33/.37, 30/.16/.081/.041/.23/.23/.12/.15/.13/.16/.21/.10, 50/.097/.027/.034/.064/.043/.017/.16/.041/.065/.11 /.03, 70/.057/.02/.031/.035/.027/.023/.11/.032/.036/.064</p>	N/A

SITE	REMARKS	DART
37-329 #5	<p>.024, 90/.036/.031/.021/.032/.057/.041/.12/.019/.019/.04 9/.031. Soffit; surv.1- long. cracks coincident with sonovoid tubes, some with leach stains. Surv.2- long. cr. = 1700m, random cr.=45m, very leaching. Wet areas = 67m = 1.6%, spalls = 5m. Surface; surv.1- long. cracks (592m-a., 275m-v.) coincident with sonovoid tubes. Light to moderate scaling over 100% of deck area, rust stains with ERR <1m. 36 cores, 17 cores with rebar, 7 with corrosion. Surv.2- trans. cr.= 75m, long. cr. = 4025m, random/diagonal = 137m. 32% of the cracks are wide. Extensive surface wear down to the coarse aggregate. 0.7%<-0.45 V CSE.</p> <p>Concrete cover min =29, max.=64mm, 11% area cover <30mm, 75% area cover 30-50mm. Air content = 5.7,6.1,7.7%. P'C = 40.6,46.8 MPa. Chlorides, 10/.34/.46/.39,30/.3/.2/.57,50/.15/.052/.38, 70/.036/.018/.25,90/.014/.015/. Soffit; surv.1-long. cr. between girders at midspan. Surv.2- trans. cr. =13m, long. cr. =110m, random =8m, spalls =0.6m. Total of 21m of long. cr. u/s prestress beams. Surface; surv.1- 3/6 cores with rebar that is corroding. Surv.2- trans. cr.-nar. =1m, long. cr.-nar. =23m, med. =3m, wide =12m, diag.-nar. =18m,med. =18.5m, wide =20m, rand.-nar. =1m. No scaling but wearing to expose aggregate in wheel lines. 0.8%<-0.45 V CSE.</p>	N/A

SITE	REMARKS	DART
37-335	<p>Concrete cover min.=28, max.=55. F'c = 44.7, 51.3, 51.9, 51.9MPa. Chloride: 10/0.20/.235/.161, 30/0.169/.22/.078, 50/0.117/.124/.044, 70/0.026/.045/.031, 90/0.015/.013/.033%. Asphalt thickness min.=70, max.=120, avg.=90mm. W/P is rubber. asphaltic membrane- becoming brittle. Soffit is spalled over .8% of area and 285m of cracks were recorded, 55% had evidence of water penetra. Conc. surface was wet at the curb. 11/20 cores had surface delam. up to 45mm. These cores in areas of high corr. potent. Asp. sample area wet in 4/7, delam. in 3/7 up to 80%.</p>	N/A
37-341 EBC	<p>Concrete cover, min.=47, max.=100mm. 97.1% of deck area cover>50mm. Chloride: 10/0.685, 30/0.434, 50/0.247, 70/0.135, 90/0.045%. Soffit and surface in good condition.</p>	N/A
37-341 EBL	<p>Concrete cover min.=30, max.=125mm. Cover<50mm specified over 3% of deck. F'c =32.9/43.2MPa. Chloride: 10/0.314/0.361, 30/0.131/0.255, 50/0.031/0.065, 70/0.017/0.022, 90/0.016. Surface is worn to expose coarse agg. Soffit is wet at S. exp. jt., cracks on W. side /rust with efflor. along N. exp. jt. Soffit same for surv.2, slightly worse.</p>	N/A
37-323	<p>Concrete cover min.= 25, max.= 95mm, 87% area cover >50mm. Air content = 4.3%, s.s.=22.1 and s.f.=0.24 just outside acceptable parameters. F'c = 68.4, 69.9</p>	N/A

SITE	REMARKS	DART
	Mpa, surv.1 only. Chlorides, 10/.245/.082//.323//.120,30/.106/.025//.123//.019, 50/.025/.018//.018//.013,70/.019/.015//.014//.013, 90/.015/.016//.013//.013. Soffit; surv.1-extensive long. cracking (1083m), some with leach stains (22.5m), run parallel to metal void tubes. Spall and delam.(0.1m,1.6m) at corner at E. exp. jt. Surv.2- no real change. Surface; surv.1- extensive longitudinal cracking (1.34 not long.)parallel to metal void tubes, n =467m, m=166.5m, v=13.3m. 15 cores with rebar, 7 with slighted rusted rebar. Surv.2- extensive long. cr., n=543m, m=505m, v=29.5m (14 not long.). 4 cores with rebar, 1 slighted rusted. 14< -0.45 V CSE. Concrete cover min.=25, max.=100mm. f'c = 58.3,61.8,68/52.1,54.4 MPa. Chlorides, 10/0.388,30/0.475,50/0.287,70/0.133,90/0.056t. Soffit; surv.1- one spall at N-end. Surv.2- 44m of cracks, 28% are efflor. stained. Spall at north end = 1m, with ERB. Surface; surv.1- few random long. cracks. Surv.2- numerous long. cracks, narrow =75m, medium =35m.	N/A
37-805	Concrete cover min.= 25, max.= 65mm. Air content= 4.9%, spacing factor and specific surface are outside acceptable parameters. f'c= 41,46,47,52.2,61.1 MPa. Chlorides, 10//.058//.051,30//.029//.017,50//.021//.013, 70//.019//.006,90//.01//.005. Asphalt thickness min.= 60, max.= 90, avg.= 70mm. W/P is a mastic membrane, 4mm, partially bonded.	N/A

SITE	REMARKS	DART
03-069	<p>Soffit, good, 57.1m of trans. cracking, 2.2% area is wet. Surface, 17 cores, 9 asphalt samples. Horizontal crack at rebar- 1, slight corrosion of rebar- 3, severe corrosion of rebar with horz. cracking- 1, scaling and cracking- 1, 4 areas were damp, 3 were 1. scaled, 1 was del.</p> <p>Concrete cover min.=25, max.=36mm. Air content = 5.3/10.7%, but specific surface and spacing factor are outside acceptable parameters. f'c = 29,33.5 MPa. Chloride depth 10/.187/.07,30/.166/.027,50/.124/.023, 70/.07/.021,90/.048/.014., survey 1 only. Asphalt thickness min.=60, max.=90, avg.= 77mm. W/P is fiberboard with good bond to conc., 4mm. Soffit; surv.1- numerous n. short trans. cracks on either side of central st. beam, one small spall with ERB, several long. and trans. with effl. in north span. Surv.2- Additional 29m of long. cracks and 28m of trans. cracks. Long. are stained or leached, mainly u/s curb and median in n. span, 0.5% increase wet areas. Surface; good in surv.1, surv.2- 6/10 asp. samples with scaling, 1/10 was moist, 1/10 had a long. crack, 7/10 were adjacent to curbs.(wet and scaled ones). 18.3%-0.45VCSE.</p>	N/A
03-224	<p>Concrete cover min.=25, max.=43mm. Air content 3.5,4.6,7.8%, but spacing factor and</p>	N/A

SITE	REMARKS	DART
03-225	<p>specific surface are outside acceptable parameters. f'c = 27.8, 35, 43.1 MPa. Chloride depth 10/.321/.351/.089, 30/.216/.231/.036, 50/.132/.123/.024, 70/.172/.119/.014, 90/.083/.065/ 012. higher test cores at a crack in the deck or two higher test cores at a crack in the deck or high VSE. Asphalt thickness min.=65, max.=100, avg.=77mm. No w/p, bond of asp. to conc. is fair to poor. Soffit, numerous short trans. cracks with efflor., most often located under median or SBL. In surv. 2, 42m of extra trans. cracks and small areas are wet, HC and spalled. Surface; surv. 1- damp in 1/5 samples, sample at a crack location. Del. to 25mm in 1/19 cores. Surv. 2- narrow trans. crack and a long. crack found in 2/10 samples. Piers are in poor condition many cracks and severe spalling with ERB. Concrete cover min.=24, max.=57mm. Air content = 4/6.4%, spacing factor and specific surface outside acceptable parameters. f'c = 37.8, 38.5 MPa. Chloride depth 10/.053/.016, 30/.023/.01, 50/.01/.008, 70/.015/.008, 90/.21/.008. Asphalt thickness min.=60, max.=110, avg.=80mm. Good bond to conc., no w/p in either survey. Soffit, surv. 1- numerous short trans. cracks, most located under s/w, these are efflor. leaching. Surv. 2- 11m of additional cracking was recorded, these are mainly in the transverse direction. At both the north and south exp. joints, the u/s of deck has spalled with rusted ERB. Surface; surv. 1- only 1/11 core with 10mm delam. Surv. 2- bond of asphalt was generally poor, one long. and one trans. crack recorded in 2/10</p>	N/A

SITE	REMARKS	DART
03-265 EBL	asphalt samples. No cores taken or tested. Concrete cover min.=20, max.=65mm. Air content =5.8%. F'c = 45,50.4,53.3,53.7 MPa. Chlorides, 10/.064/.12,30/.026/.077,50/.013/.016, 70/.004/.004/.004, 110/.004/.004. Asphalt thickness min.=60, max.=100, avg.=73mm. W/P is a rubberized asphalt with protection board, bond is fair to poor, t = 4mm. Sofit, A few vet (8.8m) and rust stained areas, many short fine trans. cracks on u/s curbs. Surface, 1.-m. scaling 4/12 cores, 3/8 samples water between the W/P and the prot. board. Concrete cover min.=40, max.=80mm. Transverse avg.=100mm. F'c varies 60,59.4MPa, first survey only. Chloride depth,10/.081/.141,30/.092/.061,50/.061/.032, 70/.02/.017,90/.019/.007, first surv.only. Asphalt thickness min.=100, max.=155, avg.=125mm. W/P is fiberglass strands in mastic membrane, t=1-10mm. Sofit has many areas of map cracking - damp, areas of delam. and spalling with ERB, const.jt.is leaching. Conc. surface is 1-m scaled in sample areas, some delam. found in second survey.	N/A
07-023	Concrete cover min.=70, max.=135mm. (to dep for cover:metre) F'c = 45.9, 46.3MPa. Chloride depth, 10/.074/.093,30/.025/.066,50/.019/.041, 70/.014/.020,90/.022/.022 surv.1 only Asphalt thickness, min.=20, max.=80, avg.=55mm, surv.1.	N/A

SITE	REMARKS	DART
07-054	<p>Surv.2 - min.=35, max.=100, avg.=70mm. No w/p in surv.1, mastic membrane, 2mm, in surv.2. Rubber sheet 1mm thick found over joint in surv.2. soffit; surv.1- numerous trans cracks, several with efflor. staining. Surv.2- damp over 15.7% of area, 49% of cracks, 55% of cracks leached or stained. W. coping is severely scaled. Abutments, ballst walls and bearing seats undergoing heavy to severe scaling exposing rebar, spalling also occurring. 3/8 cores, horz. cracking surface; surv.1- delam. 100mm depth. Rebar severely at rebar or at 100mm depth. Full vert. crack 1/8 corroded in 1 core at delam. Full vert. crack 1/8 cores.Surv.2- adjacent to curbs surface is heavily scaled and wet. Deck drains paved over on west side, under sidewalk on east side. 8.3% of deck half-cells <-.045VCSE.</p>	N/A
	RF DECK EXTENSIONS ADDED ON IN 1948 EACH SIDE OF ORIGINAL STEEL BEAM STRUCTURE CONSTRUCTED IN 14. Concrete cover min.=65, max.=95. Air measured, surv.1- 5%, spacing factor and specific surface fall outside acceptable parameters. F/c, old = 36.3MPa, new = 30.2MPa. Chloride depth, old- 10/.008, 30/.005, 50,70,90/.005. New- 10/.146,30/.089,50/.06,70/.043,90/.026. Asphalt thickness, old- min.=185, max.=215, avg.=203mm. New- min.=25, max.=90, avg.=54mm. W/P is a mastic membrane, 2mm. Surface was repaved after the 1981 survey. Two long. cracks above joints between the old and new structures. Soffit, old structure is hidden by semi-circular corrugated steel pipes cut in half for formwork.	

SITE

REMARKS

Outside pipes, both sides, are severely rusted, remainder are moderately rusted especially along connections to the beams. Bottom flanges of beams are moderately to severely rusted in surv.1, and just severe in surv.2. Rigid frames have numerous trans., long, and random cracks, some contain efflor., and are associated with wet areas. Original deck is 130mm higher than new extensions. Surface, light scaling on old deck surface.

07-055

Concrete cover min.=15, max.=75mm.
Air content = 3.7%, spacing factor and specific surface were outside acceptable limits.
f'c = 53.1, 57.9, 60.9 MPa.
Chlorides, 10/.01/.023, 30/.007/.013, 50/.006/.009, 70/.004/.008, 90/.004/.004. Surv.1 only.
Asphalt thickness min.=80, max.=115, avg.=95mm.
Bond to concrete was poor both surveys.
Soffit; surv.1- good, rusted rebar chairs on u/s.
Surv.2- Few long. cracks over pier beams (10m), number of wet spots in center spans (15m).irc.
Surface; surv.1- slightly rusted rebar 3/17 cores, rake finish, 4/4 sample areas damp.
Surv.2- 3/6 sample areas wet. No deck drains.

Delaminated = 7.6%

07-056 WBL

N/A

Concrete cover min.= 65, max.= 88mm. Cover readings also in order of 120mm.
Air content = 5.1, 7.1%, but spacing factor and specific surface are outside acceptable parameters. f'c = 23.6, 27.5 MPa.
Chlorides, 10/.04/.035, 30/.031/.028, 50/.033/.029, 70/.032/.023, 90/.028/.022.
Asphalt thickness min.=45, max.=120, avg.=68mm.
W/p recorded in surv.1 as asphalt cement of 1mm, in surv.2 no w/p was recorded.
Soffit; surv.1- 9 long. cracks, 4 with efflor.
Surv.2- 13m of new long. cracks, 1m of wet area.

DART

SITE	REMARKS	DART
07-059	Surface was good in surv.1, 3/3 samples wet in surv.2, 2/3 samples were 1. scaled, no cores in 2. Concrete cover min.=10, max.=50. Long.=45/135. Air content of first survey =2.1% and 6.2% but specific surface and spacing factor outside acceptable parameters first surv. only. F'c varies 25.9,33.4MPa. Chloride depth,10/.049/.12,30/.039/.101,50/.035/.044, 70/.025/.04,90/.026/.035., first surv. only. Asphalt thickness min.=90, max.=125, avg.=105mm. W/P is mastic membrane t=2-4mm. Soffit has numerous long. cracks, some are damp and are leaching. Surface 2/3 samples 1. scaling, damp in surv.2 N/A	N/A
07-069 07-070	Concrete cover min.=25, max.=70mm, covern in median = 135mm. Chlorides, 10/.097/.211//.289//.211,30/.107/.227//.168//.363, 50/.074/.159//.136//.209,70/.060/.049//.135//.171, 90/.038/.036//.134//.061. Air 9.7%, spacing factor and specific surface are not acceptable. F'c varies 25.9,27.2,27.2/38.2,40,40.2 MPa. Asphalt thickness min.=45,max.=80, avg.=60mm. W/P is mastic membrane with fiberboard, t (w/p)=5mm. Higher corrosion potential areas ate in exposed concrete median and shoulders. Soffit has numerous trans. cracks, majority with efflorescence located generally in centre span. Several new trans. cracks in second survey with eff. Full depth vertical cracksin three cores.	N/A N/A

SITE	REMARKS	DART
07-071	Surface good in surv.1 and 2, 3/18 cores with full depth cracks. Concrete cover min=18, max=65 mm, note only 2 measurements. F'c= 20, 31.8 MPa. Asphalt thickness min=51, max=120, avg=75 mm. Soffit; surv.1- trans. cr.= 6m, long. cr.= 82m. Surface; surv.1- 7 cores, 3/7 fair, 4/7 good. 5 samples, 1/5 with slight disint., 4/5 good.	N/A
11-019	Concrete cover min.=0, max.=79mm. In two asphalt samples rebar was found at the deck surface. F'c = 25.9, 27.5 MPa. Chlorides, 10/.083/.156, 30/.042/.083, 50/.037/.045, 70/.039/.035, 90/.033/.029. Surv. 1 only. Asphalt thickness min.=120, max.=180, avg.=147mm. W/P is a mastic asphalt, t = 0-3mm, fair bond. Joints at piers filled with bituminous filler. Soffit; surv.1- numerous short random oriented cracks; majority with effl. Spalls with ERB along the joints at piers. Surv.2- Large areas of spalling with ERB, at joints and both centre piers and deck drains (7m), wet areas = 6m, trans. cr. = 166m, 75.7% are leached. Long. cr. =43.2m, 37% are leached. Heavy rust staining along top flange of beams, copings are severely spalled with ERB. Surface; surv.1- 1.-h. scaling 7/7 cores, 1/7 with hor. cracking 1/7 with poor bond between agg. and cement. Samples 3/3 m. scaling. Surv.2- entire sample delam. and spalled 2/8 samples (at joints), with ERB, 1. scaling 2/8. Surface was dry. t=175mm, 24<-0.45VCSE. Concrete cover min.=60, max.=120mm. F'c = 31.5, 23.3/33.8, 34.6, 47.6 MPa.	N/A
11-164		N/A

SITE	REMARKS	DART
11-174	<p>Chlorides, 10//.065//.067//.062/.031//.019, 30//.024//.134/.02/.012/.013.50//.013//.112/.008/. 012/.005. 70//.009//.078//.007//.006/.005.90//.006//.056/.006/ .005/.006. Asphalt thickness min.=75, max.=156, avg.=136mm. W/P is mastic membrane, t=4mm. Soffit; surv.1- Numerous trans. and long. cracks with efflor.; many in wet areas, one spall with ERB at wet area at east end. Surv.2- Same as 1, more wet areas, trans. cr.= 148.4m, 50% efflor., long. cr.= 40.4m, 25% efflor., wet areas= 40.6m, spalls= 6.5m with ERB. Surface; surv.1- all cores good, 1/5 samples h. scaling, above wet area on u/s. Surv.2- 3/11 cores with deterioration, delam-1, spalls- 2, 1/5 samples damp and del.(at curb) Concrete cover min.=40, max.=120mm. F'c = 29.1, 29.8/45, 49.1 MPa. Chlorides, 10/.049/.061//.060.30/.03/.059//.034, 50/.031/.04//.025, 70/.028/.036//.018, 90/.029/.038/ /.024. Asphalt thickness min.=60, max.=270, avg.=165mm. W/P is a mastic membrane, t=3-4mm. Soffit; surv.1- Numerous long. Cracks with efflor. One wet area at long. crack in WBL. Surv.2- 24.5m of efflor. cracks, mainly long., 17m ddry cracks. 7.8m of spalls. Surface; surv.1- good. Surv.2- 1/8 cores with delam. 10-50mm at surface, 1/4 samples with m. scaling. Concrete cover min.=33, max.=52mm. Air content of first survey was 7.8%, spacing factor and specific surface outside of range (0.15mm/24.0).</p>	N/A
11-220		N/A

SITE	REMARKS	DART
11-257	<p>F'c varies 20.9, 22.8/33.4, 35.7MPa. Chloride depth, 10/.054/.027//.04, 30/.037/.029//.05, 50/.035/.024//.032, 70/.032/.026//.036, 90/.027/.025//.01. Asphalt thickness min.=102, max.=137, avg.=118mm. Soffit, numerous short transverse cracks on u/s of safety walks. 50-70% of cracks are efflorescence.</p> <p>Two small wet areas with ERB. Surface; surv.1- 1/7 cores was delam., also in high half-cell area. Surv.2- was good. Concrete cover min=55, max=66 mm. Air content= 3, 3.4%, s.s.=24.7, 31.2, s.z.=.27, .198. F'c= 36.3, 48.9 MPa. Chlorides; 10//0//.008, 30//.0//.0, 50//.001//.005, 70//.001//.012, 90//.001//.014. soffit; surv.2- good cond., narrow long. and diagonal stress Cr. close to the abutments and at pier 3. Surfaces; surv.2- 20 cores, 18/20 good, 10 samples, all good. Concrete cover min.=32, max.=90mm. F'c = 20.6, 23.8/24.6 MPa. Chlorides, 10/.155/.099//.086, 30/.128/.132//.049, 50/.109/.115//.041, 70/.08/.073//.029, 90/.056/.035//.018. Asphalt thickness min.=100, max.=200, avg.=160 mm.</p>	N/A
16-018	<p>Bond between asphalt and concrete is poor. Soffit; surv.1- 80% of u/s is honeycombed. Few cracks with efflor. in each span. One area at s-e span which is damp with ERB and cracks with efflor. SURV.2- Several lg. cracks adjacent to the pier with efflor. (16.3m) several areas of spalling (1.6%) and 1. scaling. Some areas of H.C.</p>	N/A

SITE

DART

REMARKS

with corroded ERB. Lg. damp areas (9.3%) on east span, especially north side at pier. Fascia is scaled in several locations.
Surface: surv.1- M. scaling 2/6 cores, 1/3 samples. L. scaling 1/6 cores. Surv.2- 10 cores and 5 samples taken, all with signs of deterioration. Samples- all wet and severely scaled with disintegration (up to 40mm), cracks in the surface in 3/5.
Cores- delam. 4/10, top 55mm disint. 2/10, severely scaled 4/10, corroding rebar in all with rebar(5), horz. cracks 3/10, vert. cr. 1/10, delam. at rebar 1/10.
Concrete cover min.=25, max.=65mm.
F'c = 18,23.6 MPa. 10/107/.037,30/.11/.029,50/.055/.033, Chlorides, 10/.035,90/.039/.027. Surv.1 only.
70/.049/.035,90/.039/.027. Surv.1 only.
Asphalt thickness min.=35, max.=65, avg.=50.
W/p surv.1- rubberized asphalt, surv.2- sand and asphalt mix, very thin. I did the second survey and remember a dispute over the type of w/p. Region agreed with us after we sent a sample.
Soffit: surv.1- good, two short trans. cracks with efflor. Numerous trans. on u/s of south sidewalk, most with efflor.
Surv.2- damp or leached areas=94.7m especially at drain locations, spalls=0.4m, delam.=0.8m, 36.2m of cracks with efflor. mostly trans., map cracking=10m damp.
Surface: surv.1- cores, horz. crack 1/9, vert. crack full depth 1/9. Samples, 2/4 trans. rust stained cracks, one with 25mm delam. along crack. Remaining 2/4 with 1. scaling and wet.
Surv.2- 1-m scaling in all samples, 1/3 damp. 8.3%<-0.45VCSL.

N/A

16-103

N/A

Concrete cover min.=30, max.=60.

16-114

SITE

REMARKS

Air cont. = 5.7/6.5%, but spacing factor and specific surface outside acceptable parameters. F'c = 22.9, 24.8/29.8, 37.2MPa. Chloride depths, 10/0.099//0.166, 30/0.061//0.158, 50/0.51//0.137, 70/0.046//0.113, 90/0.042//0.109. Chlorides surv. 2, corrected for background chl. 10/0.115, 30/0.122, 50/0.082, 70/0.022. W/p is rubberized mastic membrane 2-5mm. Asphalt thickness min. = 90, max. = 135, avg. = 112mm. Soffit; surv. 1- has numerous short long. cracks at deck ends; with wet areas. Surv. 2, additional 3 coincident with wet areas. Surv. 2, additional 3 small wet areas, cracks with efflor. and one area of spalling. Surface; surv. 1- had some scaling and shallow spalls with ERB (1 core) in surv. 1. Surv. 2- one sample was wet with extensive spalling and ERB, one core with delam and delam vert. crack.

Concrete cover min. = 19, max. = 85. Air content = 3.1%, spacing factor outside acceptable parameters. F'c = 30.2, 41/29.6 MPa. Chlorides, 10/.24/.18//.189, 30/.23/.17//.168, 50/.15/.13//.132, 70/.093/.099//.094, 90/.064/.079//.115. Asphalt thickness min. = 60, max. = 100, avg. = 85mm. Soffit; surv. 1- Several short cracks with efflor. adjacent to abutments. Surv. 2- Long. const. joint is efflor. at midspan, several delam. (1.5m) and H.C. areas (0.3m). U/s of bot. slab box, numerous trans. (408m) cracks, few long. (30.8), few with efflor. Surface; surv. 1- Rough in all cores, 1/1 sample 75% delam. Surv. 2- Poor along west median edge, curbs and exp. dams. Core at median, top 55mm severely scaled, 3/4

16-130

N/A

DART

SITE	REMARKS	DART
16-137	<p>samples at curbs or jt., all areas damp, m-s scaled, damp with rust staining on the surface. t=255mm. 8.2%<-0.45VCSE. NOTE HALF-CELLS INCLUDE MEDIAN AREA, TOTAL AREA=726.2M, ALL HIGH READINGS ARE IN THE MEDIAN.(3M X 38.38M = 115M) Concrete cover min.=33, max.=69mm, Air content = 7.4, 8.7, specific surface under acceptable limits, 20.1, 22.9. F'c = 29.9, 31 MPa. Chlorides, 3 cores almost identical readings of .005% entire depth. One core at high CSE reading with higher chlorides, 10/.026,30/.025,50/.073,70/.056,90/.112. Asphalt thickness min.=80, max.=110, avg.=78mm. Soffit; surv.1- several trans cr. between girders, numerous short trans. cr. on u/s of curbs, with efflor. Surface; surv.1- good, 1/5 samples with med. scaling.</p>	N/A
16-155 17-058	<p>N/A Concrete cover min.=64, max.=105mm, surv.1 only. F'c = 31.9, 33.1 MPa. Chlorides, 10/.393/.124//.096//.095,30/.29/.13//.088//.072, 50/.161/.098//.065//.034,70/.125/.049//.031//.026, 90/.035/.03//.021//.019. Asphalt thickness min.=50, max.=75mm surv.1, surv.2- min.=32, max.=82mm. W/P is a mastic membrane (t=5mm) with rubber sheet, bond-good. Soffit; surv.1- two of the long. constr. jt. display efflor. Wet are at north jt., one spall with ERB at centreline jt. near pier. Surv.2- trans. cr.=11m, open spalls=1.2m, 45% of construction jt. are efflorescence stained. Surface; surv.1- good, 1/3 samples wet. Surv.2- 6</p>	<p>N/A 1988 DART Delam.=11.2% Scaling =12.7% Debonding =2.3% Good =13.9%</p>

SITE	REMARKS	DART
17-061	cores, 1/6 poor, 5/6 good. 6 samples, 3/6 fair, 3/6 good. 4 deck area <-0.45 V CSE in surv.2. Concrete cover min=20, max.=110 for trans., min.=40, max.=125 for long. In survey two, avg.=41, min.=25, max.=60mm. f'c=28.5,36.1MPa surv. one only. Air cont. 5.6 and 7.9% in surv. one, spacing factor and specific surface outside acceptable values. Chloride penetr.10/0.013/0.039,30/0.006/0.016,50/0.007/0.007, 70/0.007/0.005,90/0.007/0.005%, surv. one only. Asphalt thickness min.=40, max.=80, avg.=62mm. Soffit for surv. one, several trans. cracks on u/s boxes at midspan with efflores. For surv. two numerous trans crack on u/s of deck, some efflores. and wet areas. Conc. deck surface was m-h scaled and rust stained at high potent. areas and damp at curb loc. for surv. two.	N/A
17-065 WBL	Concrete cover min.=50, max.=80. Air content 11,12.3%, but specific surface is outside acceptable parameters, surv.1 only. f'c=17,19.9 Mpa, surv.1 only. Chloride depth 10/.047/.062,30/.034/.082,50/.029/.047, 70/.028/.041,90/.021/.033. Asphalt thickness min.=55, max.=95, avg.=87mm., surv.1 Surv.2- min.= 75, max.=155, avg.=135mm. W/P is a rubberized mastic membrane, 2-4mm, bond was good.	N/A

DART

REMARKS

SITE

Soffit; surv.1- Random long. and trans. cracks throughout, few with efflor. buildup. Surv.2- Nev wet areas along the const. joint and at the vest drains. Total wet area = 7.5%. Few additional cracks adjacent to const. joint at centre of span.

Surface is rough, in 1/3 samples crack in asphalt also goes into deck, damp adjacent to curbs in surv.2.

N/A

17-074 WBL

Concrete cover min.=65, max.=110.
Air content = 11.5, 12.5%, but specific surface falls outside acceptable limits. F'C = 6.9, 24 MPa.

Chloride depth
10/.058/.056, 30/.029/.039, 50/.024/.032,
70/.023/.022, 90/.018/.021.

Asphalt thickness min.=90, max.=130, avg.=104mm.
W/P is a 3mm mastic membrane with a fiberglass

mat.

Mat. is good in both surveys.
Soffit; surv.1- one long. crack at end of deck near long. const. jt. Surv.2- 2 long. cracks accompanied by efflorescence and wet areas. Wet at drain locations and at w. end of const. jt. Wide trans. cracks over E. and W. abutments. Surface, good, in surv.2, wet adjacent to curbs.

N/A

17-077 WBL

Concrete cover min.=34, max.=95mm.
Air content = 3.6%, spacing factor and specific surface fall outside acceptable parameters. F'C = 27.2, 32.6 MPa surv.1 only.

Chlorides, surv.1 only

10/.084/.037, 30/.073/.028, 50/.062/.029,
70/.059/.023, 90/.06/.022.

Asphalt thickness min.=25, max.=100, avg.=57mm.
W/P is mastic and fiberglass mat, 2-3mm, good bond..

SITE	REMARKS	DART
26-117	<p>Soffit/ surv.1- Full length long. crack, several trans. cracks at midspan, 3 wet areas on east side. Surv.2- additional 11m of trans. cracking and 5m of long. cracking, 1.5m of wet areas few small spalls. Surface/ surv.1- 1. scaling 1/6 cores, vert. cr. 1/6 cores. Samples all good. Surv.2- No cores, sample areas were good. Concrete cover min.=30, max.=50mm, surv.1 only. F'C = 43 MPa. Chlorides, 10/.067//.154,30/.016//.076,50/.01//.018, 70/.008//.001,90/.01//.0. Asphalt thickness min.=65, max.=125, avg.=89mm. W/P is mastic membrane, t=1-2mm, good bond. Soffit/ surv.1- good except near abutments, spalls (8m) with wet (12m) and rust stained areas. 15m trans. cr. and 15m long. cr., all cr. leaching. Surv.2- generally good, minor det. Surface/ surv.1- good, surv.2- good.</p>	N/A
28-011	<p>Concrete cover min.=72, max.=150mm. F'C = 51.9,59/52.5MPa. Chloride depth, 10/0.084//0.102,30/0.051//0.061, 50/0.048//0.045,70/0.043//0.025,90/0.052//0.021. Asphalt thickness min.=110, max.=188, avg.=145mm. Soffit has few long. cracks extending full length under centre of ea. lane. Minor efflor. and rust staining at deck drains. In surv.2 found a few area of ERB, honeycomb also noted. Surface has 1. scaling 2/7 cores, all surfaces rough. In surv.2, surface wet in all asp. samples. Concrete deck on steel beams over main span and T-beam supported approach slabs. Concrete cover min.=22, max.=60mm. Chloride</p>	N/A
29-056	<p></p>	N/A

DART

REMARKS

depth, 10/0.08//0.552.30/0.036//0.329,50/0.03//0.0.26

70/0.025//0.283,90/0.018//0.238.
Asphalt thickness min.=62, max.=120, avg.=81mm.W/P on deck is rubberized asphalt membrane with protection board, t=3-4mm. tp=3mm.No w/p on appr. sl. Bond was good, several cracks in asphalt. Sofsit; surv.1- damp at deck drains, three interior panels substantial areas of dampness with leached or rust-stained trans. cracks.Surv.2- poor with large areas of 1-m scaling, numerous trans. and long. cracks, cracks stained with effl. or rebar corrosion, mostly at deck along centre of deck.
Surface; surv.1- 1. scaling on most of surface, delam with vert. cracking at on top of 2/8 cores, rust stains at rebar, delam. at these rebar loc. Spalls of 20mm in 2/4 asp. samples, 2/4 were wet, delam 2/4, horiz. cracks along rebar 2/4.Surv.2- All cores and asphalt samples show signs of detar., delam 3/7 cores, m-s scaling 2/3 asphalt sample and 2/7 core. Corroding top rebar layer 3/7 cores with cracked and delam. concrete(cores in area where half-cell 0.2-0.3V). Bottom layer corroding in 1/7 cores. T-beam conc. good except at expansion joints, scaling and damp.
Half-cells 4.64<-0.45VCSF in surv.1. 3.54 surv.2. Approach area =107.5m, 36% <-0.35VCSE, deck area=225.1m, 15.2%<-0.35VCSE.

SITE

N/A

31-020

Concrete overlay t=160mm. F'c=25.9,34.5MPa.
Surface; surv.1- dry, no w/p, poor bond with asphalt, 1-s. scaling in all locations. At least 60mm to reinforcing.
Surv.2- wet covered with thin layer of sand, rough, surface scaling. Overlay in 1971. Asphalt t=105-130mm.

SITE	REMARKS	DART
31-101	<p>Chloride depth, 10/.456/.124//.023//.068, 20/.248/.085//.015//.094, 50/.22/.045//.011//.044, 70/.139/.036//.005//.021, 90/.108/.032//.003//.011.</p> <p>Soffit fair with many exposed rebar, severe long. crack @ CL with spalls and rusted ERB along construction joint. Stalactite formations at some cracks.</p>	N/A
31-102	<p>Concrete cover min.=65, max.=76mm. F'c = 31.5, 32.3/28.2, 35.6MPa. Chlorides, 10/.142/.209//.135, 30/.092/.155//.09, 50/.057/.122//.088, 70/.037/.103//.048, 90/.041/.063 //.034.</p> <p>Asphalt thickness min.=210, max.=270, avg.=235mm. Soffit; surv.1- Several long. cracks in haunched region extending out from the abut. walls. Few long. and trans. cracks occur randomly under the WBL, several small wet areas. Surv.2- Significant increase in the number of long. cracks. Joint location displays three wet areas with efflor., 47.5 m new long. cracks, 1.74 of u/s is wet.</p> <p>Surface; Surv.1- 1/7 cores with 1. scaling. Surv.2- 3/5 samples with scaling, 2/5 had delam. with surface cracking. Note samples are 4 cores side by side, asphalt to thick.</p> <p>Concrete cover only obtainable in 2/6 of the asphalt samples, 70 and 75mm. F'c = 37.43/30.2, 46.6 MPa. Chlorides, 10/.276/.223//.101, 30/.207/.134//.071, 50/.254/.138//.057, 70/.210/.119//.039, 90/.172/.102 //.024.</p> <p>Asphalt thickness min.=90, max.=100, avg.=98mm. W/P is a rubberized membrane, 2mm, the bond is good. Soffit, numerous long. cracks along 3 long.</p>	N/A

SITE	REMARKS	DART
31-126	<p>constr. jt. Joints are partly efflor., have ERB and wet areas. The north fascia has numerous spalls and ERB. Surface is good. Conc. cover: min.=75, max.=150. Waterproofing = rubb. mastic memb., 5-10mm. Large aggregates, f'c=28.7/37 MPA, surv.1 only. Chloride depth, 10/.154/.132//.14//.065, 30/.125/.09//.097//.034, 50/.083/.048//.057//.021, 70/.063/.033//.032//.018, 90/.047/.035//.026//.01. Minor cracking on soffit. Surface also good. in surv.1 4/9 cores had vertical cracks 25-75mm deep.</p>	N/A
31-210	<p>Concrete cover min.= 20, max.= 60mm. Air content= 4.3, 8.2%, f'c= 28.9, 32.4 MPA. Chlorides measured in surv.1 only, 10/.036/.168/.294, 30/.004/.096/.162, 50/.003/.011/.103, 70/.011/.002/.093, 90/.001/.002/.110. Asphalt thickness min.=60, max.=115, avg.=85mm. W/P is a mastic membrane, 0-3mm, bond is fair to poor. Soffit has numerous trans. cracks with efflor. between beams and u/s of deck, mainly at pier no.1 and the</p>	N/A
31-211	<p>span between pier no. 2 & 3. (South half of deck) in second survey, 1.5% u/s is wet, and few areas of spalls and delam. (0.4%). Surface/ surv.1- damp in 6/8 samples, surv.2- damp in 4/5 samples, m-h scaling in 3/5 samples, no cores taken. 16% of deck area half cell more neg. than -0.450VCSE. Concrete cover min.=15, max.=75.</p>	N/A

SITE	REMARKS	DART
31-241	<p>F'c varies, 38.6/29.8, 32.9, 44.9MPa. Chloride depth, 10/.012//.0341//.273,30/.007//.023//.248, 50/.005//.021//.171,70/.005//.017//.114,90/.007//. 023//.033. Asphalt thickness min.=45, max.=120, avg.=100mm. H/P is rubb. mastic membrane. Thickness of deck=220mm. Soffit, 10% damp or wet, several lg. patches at ends, medium scaling on overhangs. Surv.1 and 2. Surv.2- Asphalt samples- deck surface delam. and rust stained where potentials >-0.450VCS. Top 55mm loose. Wet or damp in 3/9 samples. Cores- rebar in some cores rusted, cores cracked at rebar depth. These cracks also noted in first survey, also spalls at rebar. Evaluated for 50mm normal slump overlay with 90mm asphalt.</p>	
31-241	<p>Survey 1-1979 Air content was high 8.73%, could be reason for low F'c. Thickness of asphalt varies 75-90mm, avg.=75mm. H/P is rubberized mastic membrane, (weak system). Half-cell above 0.2VCSE in third span from S. only. Chloride depth, 10/.013,30/.007,50/.008,70/.004,90/.005. Soffit and surface is good.</p>	N/A
	<p>Survey 2-1987 Survey done to inspect concrete deck adjacent to abutment joints and for possible joint</p>	

SITE	REMARKS	DART
31-242	<p>replacement. Surface near joints is damp. Thickness of asphalt varies 85-280mm, avg.=125mm. Values for Bsurvey in this table are for the third survey done by McNeely in 1988.</p> <p>Survey 3-1988 Air content was high 8.0%, but F'c was normal, 28 and 29.3MPa. Concrete cover min=20, max=45mm, avg.=36mm. Chloride depth, 10/.009/.015, 30/.007/.008, 50/.005/.004, 70/.005/.003, 90/.005/.003 Asphalt has numerous, mostly sealed cracks. W/P is a mastic membrane, 5-10mm thick. Pair to good bond. Soffit is good, four minor wet areas, some minor HC and spalling. Shear blocks at abutments have totally spalled away. Thickness of concrete deck=190mm. Surface is good. Expansion joints have been paved over. Concrete cover min.=25, max= 70mm. F'c varies, 22.7, 29.2/32.7, 44.3MPa. Asphalt thickness min.=65, max.=120, avg.=85mm. W/P is mastic membrane t=1-10mm. Chloride depth, 10/.025/.033//.026//.016, 30/.015/.025//.017//.009, 50/.007/.021//.011//.004, 70/.01/.01//.007/.004, 90/.007/.006//.003//.004. Soffit is good minor cracks and spalls. Thickness of deck=175mm. Surface damp at curbs, 3/22 asp samples in surv.1.</p>	N/A
31-243	<p>Concrete cover min.=20, max.=60, avg.=32mm. Air content 4.5/7 %. F'c = 17.3, 26.1/35.3 MPa. Chlorides, 10/.092//.285//.206, 30/.062//.222//.158,</p>	1988 Dart Delaminated = 18.6%

SITE	REMARKS	DART
31-245	<p>50/.02//.168//.087,70/.011//.122//.045,90/.005//.024//.02. Asphalt thickness min.=65, max.=110, avg.=87mm. W/P; surv.1- rubberized mastic, fair bond strength. Surv.2- mastic with protection board, 5-10mm, fair bond. Soffit; Surv.1- Two wet areas at trans. constr. joint and at centre pier. Surv.2- Some trans. (19m), and long. (29m) cracks. Few trans. are leached. Six damp areas (9.5m), 2 H.C. patches. Northeast fascia is heavily spalled with corroded ERB. Surface; Surv.1- Delam. 5mm- 1/6 cores, scaling 10mm- 1/8 samples, top 30mm spalled and damp- 1/8 samples. Surv.2- Horiz. cr. at 20mm, rust at rebar- 1/10 cores, rust at rebar- 1/10 cores, horz. cr. at 10mm- 1/10 cores, Samples- damp with ERB top 20mm crumbled 3/8, delam. 2/8. 15% <-0.45 VCSE.</p>	N/A
40-082	<p>Concrete cover min.=10, max.=70mm. F'c varies from 20.7/39.8,47.5Mpa. Chloride depth. 10/.029//.02//.008,30/.014//.016//.006 50/.016//.008//.005,70/.006//.003//.005,90/.007//.003//.004. Asphalt thickness min.=65, max.=100, avg.=83mm. W/P is rubberized mastic membrane, t=3-15mm. Soffit is good, c.j. at centreline is leaching, some light to moderate trans. cracks u/s boxes. Surface- some 1. scaling 2/6 samples surv.1, and in 1/6 of surv.2. Concrete cover min.=35, max.=54. Air content is 8.6% but specific surface and</p>	N/A

SITE	REMARKS	DART
42-079 NBL 42-149	<p>spacing factor fall outside acceptable parameters. Chloride depth=50mm. 10/0.180,30/0.115,50/0.230, 70/0.003,90/0.003. Exposed concrete surface is delam. 0.3% of deck area. Deck thickness=180mm. N/A Concrete cover min.=23, max.=55mm. Bottom layer approx.=100mm. Chloride depth =50mm. 10/0.268,30/0.057, 50/0.021,70/0.005,90/0.008%. Thickness of deck = 167mm. Surface is light to medium scaled, 1.8% of deck with half-cells>0.45VCSE. Concrete cover min.=sd45, max.=75mm. Chloride depth, core tested both surveys in same area.</p>	N/A N/A
43-115	<p>10/0.034//0.074,30/0.036//0.082,50/0.039//0.076, 70/0.039//0.064,90/0.023//0.058. Asphalt thickness, min.=75, max.=110, avg.=92mm. W/P is mastic membrane, t=3mm. 9% deck area with half-cells<0.45VCSE, surv.1, 11.9% deck area with half-cells<0.45VCSE, surv.2. Soffit at east end, wet, cracked, leaching and efflor. especially at the ext. beams. Exposed, rusted shear reinforcement on beam face due to low cover. Surface was spalled in 2/7 core and 1/3 asp. samples and delam. in 1/7 cores. Surface and soffit deterioration more severe in surv.2,</p>	N/A
44-018	<p>Concrete cover min.=21, max.=68mm. 36% of deck area cover between 20-36mm, 31% of deck area between 38-50mm. Specified cover is 38mm.</p>	N/A

SITE	REMARKS	DART
44-023	<p>F'c= 35.3/31.37.1MPa.Chlorides for 1981, 10/0.179,30/0.042,50/0.005,70/-,90/0.005, for 1987, 10/0.215,30/0.185,50/0.108,70/0.043,90/0.018. Soffit in good condition, exposed conc. surface is light scaled over 17$\frac{1}{4}$ of area in first survey and is scaled over 32$\frac{1}{4}$ in second survey. Also in 1987, found 85m of narrow cracks and 24m of medium cracks on surface. Deck "t" approx.=190mm. Concrete cover min.=50, max.=100mm. Air content = 4.3$\frac{1}{4}$, spacing factor and specific surface outside acceptable parameters. F'c = 44.6 MPa.</p> <p>Chlorides, 10/.047,30/.032,50/.021,70/.016,90/.014. Asphalt thickness min.=120, max.=180, avg.=155mm. W/P is rubberized asphalt membrane, 1-3mm, layer found on top of bottom layer of asphalt and not in every core. Soffit, scaling noted along trans. const. joint. Surface, fair to poor. damp with h.-s. scaling 3/4 samples, scaling 5-25mm in 4/8 cores. Voids around coarse aggregate. 4$\frac{1}{4}$ <-0.45V CSE.</p> <p>Concrete cover min.=44, max.=73mm trans., min.=60, max.=68mm long, F'c=30.6MPa. Chloride depth 10/0.045,30/0.021,50/0.016, 70/0.014,90/0.012. Asphalt thickness min.=45, max.=84, avg.=71.4mm. W/P is hot rubberized membrane, t=4-8mm, asp. is poor. Soffit has large spalls with ERB on outside edges</p>	N/A
44-065		N/A

SITE	REMARKS	DART
44-164	<p>of the U/S of deck. Surface scaling at top of cores 5-15mm in 2/3 samples. 2/6 cores scaled, 2/6 cores delam. Half-cells for second survey, 5% <-0.45VCSF, 2 cores taken with delam = 35mm. Concrete cover =45, min =0, max=60mm, cover less than 20= 7.4 =1.1%, cover 20 to 50 =369.9 =4.1%, greater than 50 =291.7 =43.6% Air content =6.5%, spacing factor =.15 outside acceptable limits. F/c = 50.5, 51.6, 52.7 MPa. Chlorides, 10/.211/.414//.47//.254, 30/.115/.184//.257//.173/.50/.042/.064//.07//.054, 70/.039/.051//.028//.031/.90/.046/.039//.031//.036 Suffit; surv.1 -trans. cr.=6.1 with leach deposits Surv.2 -trans. cr.=2.2m, long. cr. =3.3m, other =4.1m few spalls =.21m and some exposed re-bar Surface; surv.1 -trans. cr. =6.4m, long. cr. =1.4m, diag. cr. =2.1m, 2.7%<-0.45 V CSE. Surv.2 = trans cr. =7.3m, rand. cr. =2.6m 8.5%<-0.45 V CSE.</p>	N/A
385-001	<p>Concrete cover min.=37, max.=60mm. Air content = 4.1%, spacing factor and specific surface outside acceptable parameters.. F/c = 25.3/38.4/31.4/43.4/44.7/48.4 MPa. Chlorides, 10/.21/.076//.043//.092, 30/.011/.066//.02//.081/.50/.007/.057//.011//.073, 70/.007/.031//.007//.066/.90/.024//.006//.101, 110//.096/.130//.197/.130//.249. Appears as though chlorides are increasing with depth in second core tested, core</p>	N/A

SITE	REMARKS	DART
385-002	<p>located adjacent to a curb. Asphalt thickness min.=50, max.=120, avg.=82mm. Soffit; surv.1- a number of cracks, scaling of conc. in the southern portion near the centreline of the br. along with heavy corrosion on the top flange of the beam. Spalling of concrete noted near both north and south end deck joints. surv.2- Hairline pattern cracking on entire u/s. At centre area efflor. with stalactites at cracks, some with rust staining. Bot. of coping spalled in several areas. Trans.=50m, 28¢ leached. Surface; surv.1- 7 cores, quality of conc. good, 1/7 with rebar. 9 samples, 3 with minor to heavy scaling, the remainder in good cond. surv.2- Portions of deck adjacent to both curbs have disintegrated to a depth of 25-40mm. 6/17 cores with cracks or delam. (1- sample with cracks) 3/17 cores with corroded rebar. Heavy spalling at deck cold jt. It < -0.55 VCSE, 2.54t-0.45 VCSE.</p>	
	<p>Concrete cover min.=40, max.=75mm. Air content = 4.3, spacing factor and specific surface outside except. parameters. F'c = 48.4, 50.9, 56 MPa. Chlorides, 10/.017//.129, 30/.055//.135, 50/.038//.077, 70/.034//.047, 90/.036//.036, 110//.028, corrected values depth of pen. only 30 and 50mm. Asphalt thickness min.=70, max.=100, avg.=89mm.</p>	N/A

SITE	REMARKS	DART
385-258	<p>Bond between asphalt and concrete, poor. Soffit; surv.1- good, 2-50x50x25mm holes from formwork. Surv.2- clean, dry, uncracked, 50% u/s covered with paper-like form liner used during construction. Surface; surv.1- 1/3 cores with 1. scaling, 2/2 samples moist, 1/2 samples 1. scaling. Surv.2- Portions of deck 0.5m adjacent to curbs disintegrated to a depth of 10-30mm, 1/7 cores, 2/6 samples. 1. scaling 2/7 cores, 1/7 cores with slightly rusted rebar. Higher potent. readings at curbs and ends of deck. Concrete cover min.=15, max.=50. F'c=37.6, 52.8, 54.6, 58.5MPa. Chloride, 10/0.24, 30/0.144, 50/0.101, 70/0.052, 90/0.16, 110/0.008%. Thickness of deck=245mm. Asphalt thickness min.=60, max.=85, avg.=73mm. Asphalt in poor condition. Surface is damp, 1-m scaled, found corrosion of rebar in cores, 13.6% of deck area corr. potent.>-0.45.</p>	N/A
415-074	<p>Concrete cover min.=75, max.=93mm. Air content; n/a in surv.2 F'c = 53.7/73.7 MPa. Chlorides, 10/.237//.3433, 30/.175//.2038, 50/.095//.1129, 70/.042//.0815, 90/.029//.0427. Asphalt thickness min.=48, max.=127, avg.=83mm. W/P mastic membrane, 3-5mm, brittle, fair bond. Soffit; surv.1- Wet and efflor. stains along two const. jts., 1. scaling near N. abut. Surv.2- long. Cr. =3.1m. Surface; surv.1- 2/6 cores top 20-45mm deteriorated (cores beside each other) at W. const. jt. where asp. is cracked. Moist at 2/3 samples.</p>	N/A

SITE	REMARKS	DART
45E-003	<p>surv.2-light to heavy scaling with some air voids. 6 samples, 1/6 dist. 35mm, 1/6 dist. 10-15mm, 1/6 dist. 20mm Note there is a dam under this structure at north end.</p> <p>Concrete cover min.=75, max.=105. Air content= 3.9%, spacing factor and specific surface outside acceptable parameters. F'c = 52.3/59.7 MPa. Chlorides, 10/.148//.2958//.30/.034//.2363, 50/.018//.1166,70/.007//.0465,90/.007//.0218. Asphalt thickness surv.1- min.=40, max.=67, avg.=55mm. Surv.2- min.=70, max.=120, avg.=97mm. W/P is mastic membrane, 2-4mm, brittle, poor bond. Soffit; surv.1- wet areas and heavy efflor. along two constr. joints, wet at deck drains. surv.2- numerous hairline cr. trans. Cr. =25.9m, spalls =0.35m, wet areas =23.8m. Surface; surv.1- good, 3/3 samples moist. surv.2- 5 cores, 1/5 with medium scaling. 5 samples, 1/5 with disint. 15mm, 2/5 l. scaling, 1/5 med. scaling..</p>	N/A
48C-008	<p>Concrete cover min.=38, max.=50. Air content=5.5%, spacing and specific surface outside acceptable parameters. F'c = 30.4 MPa. Chlorides, 10/.139//.162,30/.105//.125,50/.069//.095, 70/.042//.067,90/.032//.076,110/.029. Asphalt thickness min.=86, max.=115, avg.=100mm. W/P is fibre reinforced mastic membrane, fair-poor. Soffit; surv.1- North span is worse, rust stains</p>	N/A

SITE

REMARKS

DART

in this area, many trans. cracks. Wet areas at long. centreline of deck, some trans. cr. with efflor. Surv.2- Stained trans. cracking and dampness common on u/s. Dampness mainly at centre portion and along u/s of curb, rust staining in all moist areas. Surface; surv.1- 1/6 cores delam. with corroded rebar. 1/6 i. scaling, Scaling and delam. at all 3 samples, wet. Surv.2- wet and scaling along curbs and more severe deter. along ea. edge of all 3 deck joints. Handrails, approach walls severe det. Concrete cover min.=0, max.=60mm. F'c = 23.2 MPa. Chlorides, 10/389//.162,30/.332//.125, 50/.268//.095,70/.117//.067,90//.076. Asphalt thickness min.=70, max.=105, avg.=82mm. W/P is fibre board with mastic membrane, fair, 5mm. Soffit; surv.1- short trans. cr. with efflor. and rust stains, few scaled areas. North span worst condition. 1/3 areas near abutments and piers. Surv.2- same as surv.1, few more wet areas. Surface; surv.1-2/6 delam., 2/6 scaling. Surv.2- 1/3 cores with hor. cr. at 15mm, 3/3 samples deter., 1-h. scaling, 1-cracked, spalled, wet, delam., 1- severe scaling, wet no cover to rebar. Note: 1987 survey chloride results: 10/.138/.011/.220, 30/.105/.01/.396,50/.078/.009/.293,70/.063/.009/.291.

48C-011

N/A

SITE	REMARKS	DART
48C-023	90/.049/.201/.201. Concrete cover; min =33, max =115 Air content 2.1/5.4%, s.s ns s.f. outside acceptable limits. F'c =44.1/34.5, 51.3 MPa. Chloride; 10/.068//.068, 30/.066//.071, 50/.051//.039, 70/.036//.026, 90/.026//.017. Asphalt thickness; min =70, max =100, avg =79.4. WPK = bituminous layer with protective fibreboard. Soffit; surv.1- generally in good cond., some evidence of concrete repair work near the north end deck joint, some spalling near finger plate expansion joint. surv.2- no cracks, localized spalling with exposed corroding rebar beneath the finger plate expansion joint. Surface; surv.1- 4/4 cores in good cond., 1/5 sample shows severe scaling. surv.2- 12 cores, 8/12 with rebar, 3/8 with slight to med. corrosion, 1/12 det. 60mm, 1/12 scal. 20mm, 1/12 del. 80mm, 1/12 with just gravel beneath asphalt. 16.5%<-0.45 V CSE.	N/A
48C-030	Concrete cover; min =30, max =131. Air content; surv.1 =5.7, s.s. =7.0, s.f. =.56 Concrete cover min. =30, max. =48mm. Air content = 6.3%, s.s. and s.f. outside acceptable limits. F'c = Nk/40.6, 52.5, 52.8. Chlorides; 10/.130//.140//.093//.127, 30/.100,.072//.093//.089, 50/.076,.043//.081//.076,	N/A

SITE	REMARKS	DART
48C-098	70/.052,.016//.068//.057, 90/.028,.011//.061//.036, 110//.055,130//.042. Asphalt thickness; min =70, max =105, avg =87. MPK rubberized asphalt and protection board, poor to good cond. soffit; surv.1 -a few cr. but generally no signif. cr. Or deterioration. surv.2 - relatively good cond., open spalls 2.1 m, wet areas = 49.3m. Surface; surv1.-5 cores, 2/5 with rebar, 5 samples, 1/5 scaling. Surv.2 -21 cores, 12/21 with rebar, 2/12 with corrosion. 2/21 with scaling, 1/21 with on gravel underneath. 9 samples, 1/9 with rebar, 1/1 with corrosion, 1/9 spalling, 6/9 scaling. 17.9%<-0.45 V CSE.	N/A
	Concrete cover min.=30, max.=90mm. Air content = 5.05%, specific surface is below acceptable limits, marginally entrained. F/c = 46.8, 47.1/47.0 MPa. Chlorides, 10/.289/.331//.332,30/.255/.182//.233, 50/.102/.078//.064,70/.065/.008//0.0,90/ .006.//.002 Soffit, surv.- 6m of long. cr., reflect cracking in the surface suggesting deck cracked right through. 65% u/s with rusted chairs exposed, Minor trans. cracks on overhangs. surv.2-- trans. cr. =5.2m, long. cr. =6.3m, spalls =.26m. Surface, surv.1- Traces of l. scaling, 5 n.-m. cracks. no deck drains. Cores in high half-cell areas show	

SITE REMARKS DART

48C-100

N/A

corrosion of rebars, some also with delam. at this level.

surv.2- trans. cr. = 5.7m med., 2.9m wide, long.

cr. =14.3m

4.2m wide, diag. =1.7m med.

Concrete cover surv.1-min.=30, max.=80mm.

surv.2- min=3mm, max=

Air content = 5.31%, spacing factor outside

acceptable parameters, marginally entrained.

f.c = 35.8, 38.3, 43.5/38.4 Mpa.

Chlorides, 10/.103/.112//.418, 30/.092/.081//.516,

50/.049/.053//.577, 70/.031/.028//.420, 90/ .028/.013

//.336,

110/ // .259, 130/ // .17, 150/ // .102, 170/ // .029.

Asphalt thickness min.=18, max.=35, avg.=26mm.

Wearing course extensively cracked, poor bond.

Soffit; surv.1- 244m narrow long. shrinkage

cracks.

153m trans. cracks on overhang, 9m are leached.

surv.2- trans. cr. =145m, long. cr. =244m, other

=54m.

Surface; surv.1- 27 cores, 23 encountered rebar 14

of which had corroding rebar up to 10% loss,

vert. crack in 1, h. scaling up to 40mm in 8,

delam up to 55mm in 11 cores. 16 samples,

10 with deterioration. 10 moist or wet, 3 with

heavy cracking/delam. to corroding rebar. 2 with

h. scaling

with corr. rebar. 4 with heavy cracking.

1 with rusted surface with corr. rebar under.

surv.2 -10 cores, 5/10 with rebar, 1/5 mildly

corroded.

5/10 cores with top in poor cond.

12 samples, 2/12 with hairline cr., 1/12 scaling,

4/12 with

delaminations, 1/12 with long. cr., 2/12 disint.

DART
N/A

REMARKS

Concrete cover surv.1-min.=40, max.=75mm.
Air content= 4.15%, spacing factor just
outside acceptable parameters, marginal.
F'c = 37,47.5/48.0 MPa.
Chlorides, 10/.092/.093//.597,30/.05/.076//.677,
50/.021/.053//1.282,70/.019/.028//.452,
90/.008/.025//.196,110//.111,130//.058,
150//.012,170//.002.
Soffit, surv.1- 53m of long. cracks in centreline
area at pier locations, minor trans. cracks on
outside of sloped soffits.
NW and SE corner of deck, heavy rust stains,
cracking and spalling. surv.2- trans. cr. =4.3m,
long. cr. =26.2m,
spalls =0.14m.
Surface; surv.1- Cores- 7/12 with delam. (up to
35mm) and horiz. cr., heavy rust stains on many of
the cracked and delam. concrete surfaces. 5/12
with vertical crack to top level of rebar.
Surv.2 -long. cr. med. =27m, long. cr. wide =9.1m.
1.24%<-0.35V.

SITE

48C-102

N/A

48E-008

Concrete cover min.=45, max.=55mm.
F'c = 32.7, 61.6, 62.5 MPa.
Chlorides, 10/.064/.008,30/.033/.007,50/.021/.008,
70/.015/.006,90//.007.
Asphalt thickness min.=75, max.=100, avg.=87mm.
W/P mastic membrane with protection board, 3-4mm.
Soffit, 1. trans. cracking with efflor.(23m),
mild H.C.(15m), isolated spalls with ERB (4m),
wet spots(9m). Conc. cross beams are good.
Surface, 8 cores- 2/8 with internal delam.,
sq. rebars, some alkali-silica reactivity,
6 samples most with a moist deck.
Concrete posts and end walls and curbs in
very poor condition, with corroded ERB,

SITE	REMARKS	DART
48E-027	<p>abutments also poor, settlement, tight against back of beams concrete cover min.=25, max.=90mm. Appears as though the top layer is well spaced, bottom layer at approx.=200mm. Air content = 4.2%, but both spacing factor and specific surface are outside acceptable parameters. F'c = 39.4/32,39,48.5 MPa. Chlorides, 10/.296//.064,30/.252//.018,50/.225//.017, 70/.187//.016,90/.195//.011,110//.009, Asphalt thickness min.=55, max.=95, avg.=70mm. W/p = fibre reinforced mastic, 3mm, poor condition. Soffit; surv.1- 3 long. jt. wet with efflor, area adjacent to centre joint wet entire length 300-500mm each side.One long. cr. with severe effl. plus rust staining.Surv.2- long. jt. leaking over 50% of length, cracks at const. jt. are rust and wet stained with signs of delam. Surface; surv.1- 1/3 cores h. scaling, 1/3 cores l. scaling, 1/3 samples wet with h. scaling. Surv.2- 2/4 samples with heavy scaling, 1/4 with 15mm deep delam. 4/8 cores with surface scaling, 1/8 cores conc. crumbled above rebar with 25mm cover.</p>	N/A
48H-044	<p>Concrete cover; min =45, max =110. Air content = 4.8,6.4/2.6%, s.f. and s.s. outside acceptable parameters. F'c 38.1,42.4/50 MPa. Chloride; 10/.0948/.0181//.009,30/.0562//.0108//.006, 50/.0342/.0092//.003,70//.008,90//.01 Asphalt thickness min. =70, max. =100, avg. =87mm. WPK in good cond., rubberized asphalt with prot. board.</p>	N/A

SITE	REMARKS	DART
05-050	<p>Concrete cover min.=44, max.=73mm. Air content is 6.2%. F'c=41.7MPa. Chloride depth, 10/.008/.059,30/.008/.03, 50/.007/.032,70/.006/.033.Second core, the core cracked, explains higher chlorides. Asphalt thickness min.=33, max.=63mm. Age of waterproofing > 15 years, type is unknown. Soffit and deck surface are good. Joints replaced in 1974 are leaking.</p>	N/A
05-186	<p>Concrete cover, 20-35mm = 18%, 35-50mm = 69%, over 50mm = 13%. Air content = 8.4%. F'c=45.2MPa. Soffit is good, few small isolated areas of leaching and HC. Rusted rebar chairs exposed. Surface, extensive cracking since surv.1 (87m in 1.208m in 2.), old cracks have widened, both expansion joints are depressed.</p>	N/A
06-059	<p>Concrete cover min.=25, max.=65mm. Air content = 4.9/4.2%, less than acceptable value. F'c = 68.9/30.2 MPa. Chloride depth 10/.048/.049/.061//.006//.008, 30/.025/.047/.058//.006//.007,50/ // // .004, 70/ // .008//.006,90/ // .006//.011. Asphalt thickness min.=60, max.=80, avg.=74mm.</p>	N/A

SITE	REMARKS	DART
06-120	<p>Asphalt is moderately cracked. W/P is an asphalt mastic, 0-10mm thick. Soffit; surv.1- good condition, t=190mm. Leachate on u/s at south abut. surv.2- good, two trans. stained cracks at u/s at piers, few trans. stained at u/s s/v. Surface; surv.1- good. Surv.2- 3/7 cores with horiz. cracks in top 5-30mm or at rebar level.</p> <p>Concrete cover min.=20, max.=75mm. Air content =5.3%. F'c = 42.2,55.3MPa. Chloride, 10/.114/.067//.035,30/.071/.013//.006, 50/.019/.005//.001,70/.003/.004,90/.004/. Asphalt thickness min.=60, max.=100, avg.=80mm. W/P is rubberized asphalt, 3-10mm, extends up curb face. Fair bond, poor condition at drains, rubber sheet over construction joint. Soffit; surv.1 and 2- good. Surface; surv.1- good, deep scaling at s. expansion dam. Light scaling at curb and on curb face and near end dams, t=205mm. Surv.2-good.</p>	N/A
12-058	<p>Concrete cover min.=45, max.=115mm. F'c= 61.6/59.3 MPa. Chloride, 10/.156//.013,30/.143//.008, 50/.078//.003,70/.062//.002,90/.037,110/.015. Asphalt thickness min.=95, max.=155, avg.=131mm. W/P is mastic membrane, t= 3-8mm. Soffit; surv.1- has five long. cracks extending 75% of the deck length. Cracks are leached with some spalling. Surv.2- fair, several long. Cracks, delam., spalls, and damp areas= 4.2m, several areas of patches. Surface; surv.1- all three samples had surface delam. 4/7 cores also had shallow surface delam. Surv.2-</p>	N/A

SITE	REMARKS	DART
12-059	<p>2/3 cores with delam. in top 10 mm. 3/3 samples fair, 1 shallow spalls.</p> <p>Concrete cover min.=25, max.=75mm for top layer upper mat, bottom layer upper mat 85/100mm. F'c =57.9/64.9//48.3MPa. Chloride depth, 10/ //.054,30/.075//.039,50/.086//.028, 70/.082,90/.071,110/.048. Asphalt thickness min.=95, max.=160, avg.=125mm. W/P is mastic membrane t=2-6mm. Surface; surv.1- soft in 2/5 sample areas, shallow spalls, shallow delam. each side of long. c.j., 7 cores shoved delam. in up to top 20mm. Surv.2- 4/6 poor wet, top 20mm delam or spalled, 2/6 spalled easily, soft. 3/7 cores with horiz. cracks and delaminations at top to 75mm. Soffit; surv.1- along long. c.j. spalls and some leachate in centre and south spans. Many narrow cracks. Surv.2- fair, leachate stained, damp and delam at long. construction jt. damp at most deck drains. Half-cell readings, 19% of deck < -0.45 VCSE. Surv.2, 18% < -0.45 V cse.</p> <p>Concrete cover min.=0, max.=65. F'c= 65.6,66/30.9 Hpa. Chloride, 10/.104//.06,30/.079//.042,50/.063//rebar no reading,70// rebar no reading,90/.061//.015. Asphalt thickness min.=100, max.=155, avg.=115mm. Asphalt thickest at centre of bridge. W/P is mastic membrane t=3-10mm. Surface; surv.1- is damp/soft at curbs, at long c.j. conc. is fair. Surv.2- 4/6 samples with deter., top 10-30 mm spalled in 3, delam to 20mm</p>	N/A
12-060		N/A

SITE	REMARKS	DART
14-233	<p>in 1 and al 4 damp. Soffit/ surv.1- has some small spalls along longitudinal c.j., numerous small cracks some are damp, 3/4 of area patched. Surv.2- extensive narrow cracking long, and trans. and random. Most cracks are damp. C.j. with some delam. and damp spots. Large areas of patching and honeycombing. East fascia is severely spalled with exposed rebar. 5/4 deck area <-0.45 V cse.</p> <p>Concrete cover min.=14, max.=95mm. F'c = 56.8,64.7MPa. Chloride depth 10/.141,30/.037,50/.041,70/.031,90/.02. Asphalt thickness min.=50, max.=100, avg.=80mm. Bond of asphalt to concrete is poor. In surv.2, asphalt had deteer. with deep potholes and wide cracks. Soffit/ surv.1- coping has many small spalls with ERB, the centraline construction joint is rust stained leached and scalled. Surv.2- few additional short narrow leached cracks, one with stactites.Three new spalls with ERB at east end and one at southwest corner. Surface/ surv.1- 2/9 cores with delam. to 25mm, 1-h scaling 4/9 cores, rebar is lightly corroded in 6/6 cores where encountered. Asp. samples, 4/6 were wet, h-s scaling from 15-40mm deep in 5/6 areas. light rust staining on concrete surface in 2/6 samples, underlying rusted rebar was found. Half cells <-0.45vce = 56.5%. Surv.2- 1 sample wet, rust stained, easily exposed rebar and severely scaled to 30mm. 43.5%<-0.45 V cse, 11.7%<-0.55 V cse.</p>	N/A
19-229	SURVEY 2 CORROSION POTENTIALS ONLY.	N/A

DART

REMARKS

Concrete cover min.=20, max.=50mm.
Air content = 5.9%, marginally air entrained,
specific surface = 23.2 is not >24 as required.
F'c = 43.9 MPa.
Chlorides,
10/.078,30/.072,50/.073,70/.024,90/.018.
Asphalt thickness min.=30, max.=50, avg.=40mm.
W/P is a mastic asphalt, with a rubber sheet at
the
curbs. No w/p was found in the two worst asp.
samples.
Soffit has trans. cracks at the ends of the deck.
Some with leachate and rust staining. Overall
pitted
appearance. 21m of cracks.
Surface is poor where no w/p is found.
Damp, cracked,
and delam. up to 25mm. 1/6 cores delam at 10 and
30mm,
2/6 cores with vert. cracking. t=185mm.

N/A

19-230

SURV.2 CORROSION POTENTIALS ONLY.
Concrete cover min.=20, max.=75mm.
Air content = 4.9%, spacing factor and specific
outside acceptable limits. F'c = 61.8 MPa
Chlorides
10/.105/.091,30/.104/.077,50/.094/.062,
70/.090/.029,90/.024/.019.
Asphalt thickness min.=35, max.=75mm, avg.=65mm.
W/P is a rubberized asphalt membrane plus
protection board, t=3-5mm both layers, total
6-10mm. mBond to conc. good.
Soffit; surv.1- good, numerous trans. cr. at u/s
curbs.
Surface; surv.1- 10 cores , 1/10 delam. to 20mm. 3
samples, 2/3 softsurface, easily chipped, one of
these damp with rust stains on surface, cover to

SITE	REMARKS	DART
19-369	rebar = 20mm. SURVEY 2 CORROSION POT. ASP SAMPLES AND VISUAL ONLY. Concrete cover min.=20, max.=75mm. F'c= 56.9, 58.8 MPa. Chlorides, 10/.118/.066, 30/.112/.073, 50/.093/.053, 70/.078/.022, 90/.080/.013. Asphalt thickness min.=70, max.=100, avg.=85mm. W/P is an asphaltic mastic, 2-5mm, with a rubber sheet over the construction joint. Soft; survg.1- many trans. cracks (63m) between box beams, 50m with leachate. Long. constr. jt. shows signs of leaking, stains and leachate(2m). Surv.2- Trans. cracks (80m), 67m with leachate. Damp or stained areas = 23.2m, spalls = 7.1m. Surface; survg.1- soft in 4/5 samples, spalled to 30mm 1/10 cores, 2/10 cores broke horiz. at rebar, with surface scaling. Surv.2- good all 1/10 samples.	N/A
19-373	SURVEY 2 CORROSION POTENTIALS ONLY. Concrete cover min.= 30, max.= 75. Air content = 4.7%, spacing factor and specific surface are outside acceptable parameters. F'c= 49.2, 52.2 MPa. Chloride, 10/.005/.018, 30/.002/.012, 50/.003/.008, 70/.004/.008, 70/.002/.009. Asphalt thickness min.=65, max.=95, avg.=85mm. W/P is glass fibres in an asphaltic emulsion, fond to concrete is good, 2-5mm. Soft; it does not portray deter. of the deck slab(box construction), the w/s is good, group of leach. stained cracks at mid-span and another set near	N/A

SITE	REMARKS	DART
19-374	<p>the N.W. corner. There is damage to the u/s from vehicles in the eastbound lanes, and at the face of structure over the westbound lanes.</p> <p>Surface; surv.1- Soft and crumbly along the ends of the bridge. Chalky and soft to hammer blows in all samples.</p> <p>Delam. at 45mm in 1 core.</p> <p>Concrete cover min.=50, max.=95mm.</p> <p>Cover to bottom rebar only 5mm rebar badly corroded.</p> <p>Air content 1.6%, spacing factor and specific surface outside acceptable parameters.</p> <p>Chloride depth, 10/0.034, 30/0.025, 50/0.021, 70/0.013.</p> <p>Asphalt thickness min.=60, max.=115, avg.=86.5mm.</p> <p>Asphalt in poor condition. (AADT for 1974)</p> <p>Soffit has trans. cracks between box beams, signs of moisture penetration.</p> <p>Surface damp in all samples, soft and rough at top 5mm, t=265mm. Half-cell avg. surv.1=-0.04VCSE</p> <p>avg. for surv.2=-0.1VCSE, more than double.</p>	N/A
23-122	<p>Concrete cover min. =40, max. =90mm.</p> <p>Air content = 5.8%, s.f. and a.a. outside acceptable limits.</p> <p>f'c = 67.4 Mpa.</p> <p>Chlorides, 10/.244, 30/.254, 50/.240, 70/.224, 90/.163.</p> <p>Asphalt thickness min.=75, max.=130, avg.=105mm.</p> <p>W/P is a mastic membrane, t = 2-3mm, bond is fair.</p> <p>Soffit; numerous leachate stained cracks on fascia, u/s is good.</p> <p>Surface; 1/3 samples surface damp, 1/5 cores sl.</p>	N/A

SITE	REMARKS	DART
30-208	<p>rusted rebar. 2% - 0.45 V cse.</p> <p>Concrete cover min.=80, max.=225mm. Thick cover to rebar. F'c= 41.4, 43.1/42.5 MPa. Chloride, 10/.032, 30/.023, 50/.021, 70/.017, 90/.019. Surv.1 only. Asphalt thickness min.=20, max.=50, avg.=36mm. Bond of asphalt to conc. is very poor. Soffit; surv.1- numerous leach stained areas, damp and delam. and random cracks. Some spalling and leach staining along c.j. Surv.2- U/S of w. span, open spall with rusted ERB, two areas of del. in same area. Total delam.= 0.6%. Extensive areas of damp narrow pattern cracking throughout the underside, wet areas= 7.8%. Many of long. and trans. cracks are leach stained, also along th construction joints. Surface; surv.1- 4/4 samples are wet and 1-m scaled. 4/4 cores are scaled, only 1/4 with vert. cracking. Surv.2- 2/3 cores 1. scaled.</p>	N/A
33-148	<p>Concrete cover min.=55, max.=160mm. Cover was measured to be >75mm in all asphalt sample areas. Air content = 6.3, F'c= 41.6, 43.2 MPa. Chloride, 10/.092/.054, 30/.084/.053, 50/.034/.037, 70/.021/.019, 90/.013/.016.</p>	N/A

SITE	REMARKS	DART
33-149	<p>Asphalt thickness min.=65, max.=135, avg.=100mm. Bottom layer of asphalt is poor, bond to conc. is poor.</p> <p>Soffit, all long, construction joints are leaching with deposits and rust spots along them. 6 cracks not at const. jts., three extend down the frame leg.</p> <p>Surface is damp in 6/8 samples, 1- scaling in 3/8 samples.</p> <p>1 sample crackd, long, and not on a c.j.</p> <p>SURVEY 2 CORROSION POTENTIALS ONLY.</p> <p>Concrete cover min.=110, max.=150mm. Only two measurements.</p> <p>Air content = 4.2%, spacing factor and specific surface</p> <p>are outside acceptable parameters. F'c= 62.5 MPa. Chlorides,</p> <p>10/.03,30/.016,50/.016,70/.019,90/.015.</p> <p>Asphalt thickness min.=60, max.=115, avg.=95mm.</p> <p>Poor bond to concrete.</p> <p>Soffit: surv.1- some staining and efflor. along 6 trans. construction joints. A few light rust stains.</p> <p>Surface: surv.1- 1/6 cores with full depth vert. crack,</p> <p>1/3 samples with n. trans. crack. Damp in 2/3 samples.</p>	N/A
33-150 SBL	<p>Concrete cover min.=45, max.=75mm.</p> <p>Air content was 3.2%, spacing factor and specific surface outside acceptable parameters.</p> <p>Chloride depth, 10/0.092,30/0.054//0.1045,</p> <p>50/0.025//0.116,70/0.022//0.066,90/0.022//0.042, 110//0.022. Second core tested top 30mm dater.</p> <p>Asphalt thickness min.=45, max.=100, avg.=79mm.</p> <p>Asphalt in poor condition, no w/p.</p> <p>Soffit has areas of wetness, spalling and cracking.</p>	N/A

SITE	REMARKS	DART
33-151	<p>Area at centre pier to s. pier most deteriorated with deep spalls and rusted E.R.B. Heavy cracking with effl. noted in second surv. Surface was in poor condition(surv.1) in 3/10 cores and 3/5 asphalt samples. Top 20-30mm deter., m-h scaling, 4/5 sample areas were wet or damp. Surv.1-0.1% half-cell<-0.45VCSE, surv.2 increase to 3.6%.</p> <p>Concrete cover min.=30, max.=60mm. Air content = 4.6%, spacing factor and specific surface fall outside acceptable parameters. F'c = 33.5, 46.1, 57.9 MPa. Chloride, 10/.05/.064//.064,30/.029/.071//.046, 50/.018/.069//.046,70/.022/.059//.035,90/.02/.047//.029</p> <p>Asphalt thickness min.=60, max.=100, avg.=77mm. Bond of asphalt to conc. is poor. Soffit; surv.1- Few trans. cracks (39m), long. cracks (54.5m), few with efflor., wet areas =1.1% of soffit. East coping has numerous small delam. and spalls with ERB.Surv.2- 0.1% increase in wet areas, 0.5m of spalls with ERB, min. crack growth. Surface; surv.1- 6/6 samples had deter., damp, m-s. scaling with ERB- 1/6, damp, m. scaling- 3/6, dry, 1-m scaling- 2/6. Surv.2- scaling up to 5mm in 3/13 cores, all sample areas wet, 2/7 were scaled. 8% <-0.45VCSE. Concrete cover min.=35, max.75mm. Air content=3%, spacing factor and specific surface outside accept. parameters. F'c = 51.9.62.8MPa. Chloride.10/0.194//0.051//.30/0.149//0.038,50/0.11</p>	N/A
33-175		N/A

SITE	REMARKS	DART
33-176	<p>7// 0.015, 70/0.029//0.008. Values corrected for background chlorides. Surv. 1 only. Asphalt thickness min. = 70, max. = 100, avg. = 81mm. Many random sealed cracks, poor bond to concrete. Soffit: small spalls along edges of beams. Several nar. leach stained long. cracks in two s. spans. Narrow trans. leached cracks at centre pair. Damp areas with narrow, leaching cracks with stalactites in s-e corner wher high half-cell recorded. Deter. further developed in surv. 2. 3.4t area is damp. Surface: is 1-m scaled 3/5 samples, 1-severe scaling on top pf cores, 2/10 with m. horiz. cracks, 2/10 with surface disintegration (5-10mm), 1/10 totally disintegrated. Half cells <-0.45 V csa, surv. 1-7.2t, surv. 2-26.4t.</p> <p>Concrete cover min. = 5, max. = 75mm. Air content = 9.2, 11t, s.f. and s.s. outside acceptable limits. F'c = 53.3, 53.7 MPa. Chlorides, 10/.145/.106, 30/.153/.116, 50/.163/.097, 70/.087/.061, 90/.049/.039. Asphalt thickness min. = 55, max. = 125, avg. = 88mm. W/P is mastic membrane, t = 3-5mm, good bond. Soffit: good, several rust stained or honeycombed areas, rebar chairs exposed throughout u/s. Surface: good. Concrete cover min. = 15, max. = 75mm. Air content = 8.5t, s.f. and s.s. outside acceptable limits. F'c = 43.2 MPa. Chlorides,</p>	N/A
33-177		N/A

SITE	REMARKS	DART
35-005	<p>10/.168,30/.096,50/.037,70/.02,90/.018. Asphalt thickness min.=75, max.=95, avg.=85mm. W/P is thin asphalt cement mix, poor bond. Soffit; several damp areas and several leachate-stained cracks. Exposed rebar chairs. Surface; 3/4 samples damp, rust stains with delam. in one. 1/5 cores delam down to rusting rebar. Concrete cover min.= 25, max.= 55mm. F'c = 47.3, 65.8 MPa. Chlorides, 10/.309,30/.267,50/.202,70/.129, 90/.107,110/.098,130/.093,150/.098. Asphalt thickness min.=45, max.=100, avg.=70mm. W/P is mastic asphalt with a rubber membrane at the east end joint, 1-6 mm. Soffit; surv.1- narrow random cracks throughout, 0.5m spalls around deck drains, 1.8m of H.C. with ERB. Surv.2- few additional narrow trans. cracks, few new spalls adjacent to floor beams. Surface; surv.1- surface is uneven, 1. scaling 3/6 cores, delam. to 18mm in 1/6 cores. Severe scaling to top rebar, rusted rebar when exposed, in 1/4 samples, along north curb. 2.1t <-0.45V cse. Surv.2- 17.8t <-0.45 V cse, 3.3t <-0.55 V cse. Survey 2, half-cells and visual only.</p>	N/A

APPENDIX D

Salt Usage Comparison Figures for the Province of Ontario

**prepared by:
Brian Gaston
Maintenance Operations Office
Ministry of Transportation, Ontario**

Salt Usage -- Reported Quantities Salt Used per Saltable 2 Lane Km

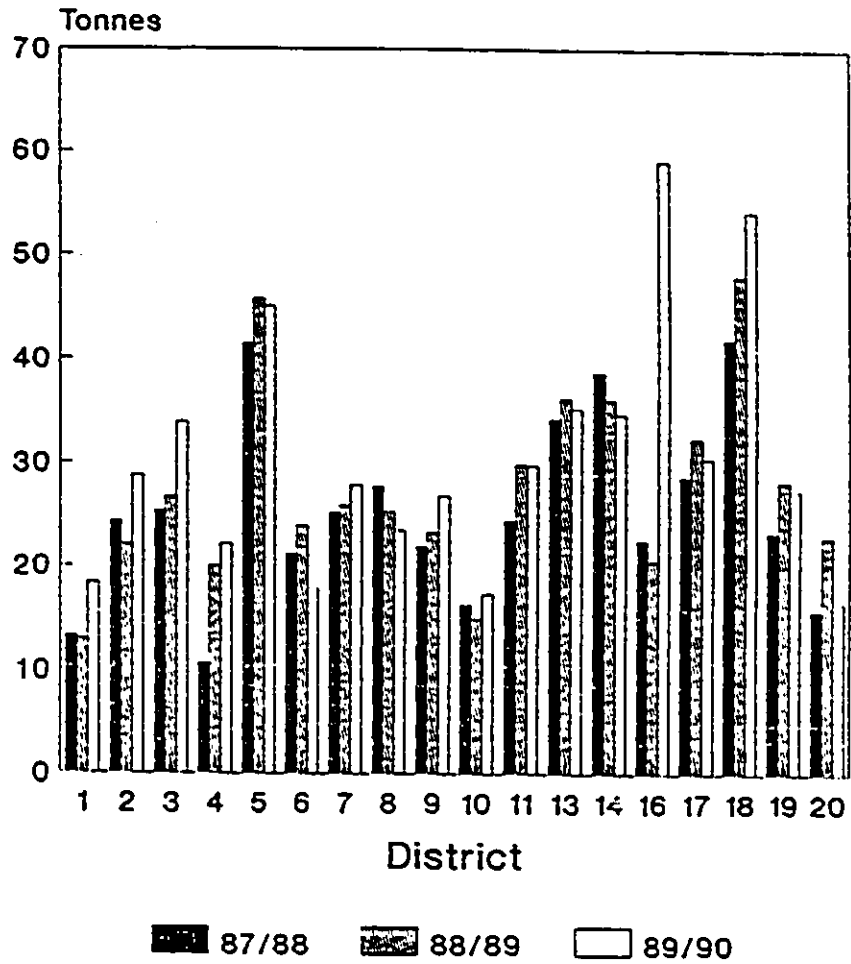
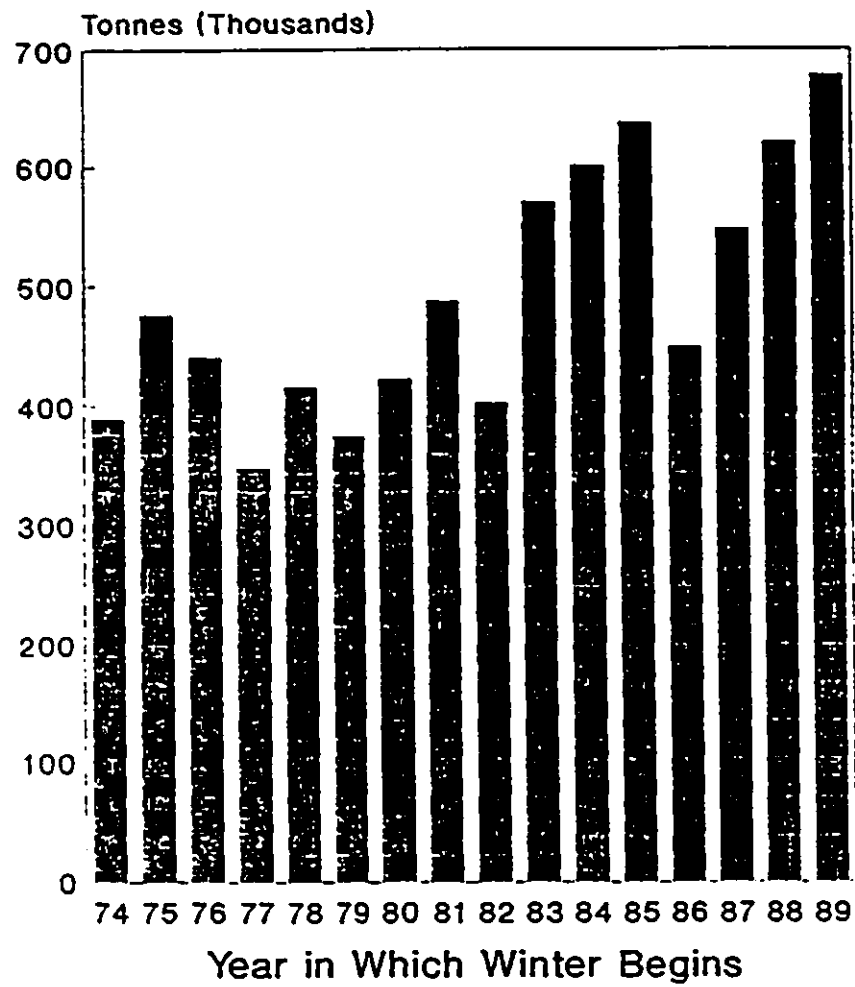


Figure D-1

Provincial Salt Usage in Tonnes 1974/5 to 1989/90



Data Supplied at Year End by Districts

Figure D-2

APPENDIX E

**Tabulated Data used in the Development of the
Rate of Deterioration vs Age set of Curves**

SITE	COVER	0 - 5	6 - 10	11 - 15	16 - 20	21 - 25
05-186	40	0.0	0.0	44.9	157.0	-
07-098	45	N/A	N/A	N/A	N/A	N/A
18-191	47	29.0	58.0	87.0	190.0	-
24-106	45	15.4	30.8	75.0	-	-
34-210	45	55.0	110.0	165.0	132.0	-
37-324#2	45	2.0	4.0	6.0	137.0	-
37-329#5	41	5.0	10.0	15.0	13.0	-
37-723	50	80.0	160.0	176.0	118.0	131.0
37-805	50	16.5	33.1	61.4	133.0	-
40-082	43	6.0	12.0	18.0	210.0	-
42-149	34	33.2	66.4	375.0	750.0	-
44-018	44	31.1	56.0	233.0	-	-
46N-219	50	86.2	172.3	258.6	344.8	360.0
18-192	55	1.9	3.8	33.1	116.0	-
22-113	54	39.6	79.2	103.0	97.0	-
24-214	72	N/A	N/A	N/A	N/A	N/A
34-193A	60	81.4	162.0	-	-	-
36-096	63	9.7	19.3	29.0	367.0	-
37-230EB	67	1.5	56.0	84.0	527.0	-
37-230WB	63	21.3	42.7	64.0	957.0	-
37-322	86	1.5	2.9	4.4	171.2	470.0
37-341EB	80	37.5	75.0	112.5	150.0	147.0
37-341EB	80	21.7	43.3	65.0	78.0	-
48C-098	70	5.3	10.6	15.9	18.0	42.0
48C-102	63	5.3	10.6	15.9	18.0	22.0
SUM		586.1	1218.0	2041.7	4684.0	1172.0
AVG.ALL		25.5	53.0	92.8	234.2	195.3
AVG. CC<=50		32.3	59.4	126.2	218.5	245.5
AVG. CC>50		20.6	45.9	52.7	249.9	165.0

Table E-1
Average Rate of Deterioration Calculations

SITE	COVER	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45
03-224	33	0	0	24.8	134	-	-	-	-	-
03-225	36	0	0	31	124	-	-	-	-	-
11-220	44	0	0	0	24.4	57	-	-	-	-
14-233	35	66.9	133.8	200.8	267.7	334.6	348	-	-	-
16-130	47	6.1	12.2	18.3	31.7	161.9	185	-	-	-
16-137	49	0	0	0	48	108	-	-	-	-
19-230	36	2.5	5	7.5	10	11.3	10	-	-	-
21-159	16	0	0	0	11	39.1	44	-	-	-
21-247	29	31.1	62.1	93.2	124.3	155.4	349.6	920	-	-
22-004	44	24.9	49.7	74.6	99.4	124.6	149.1	169	626	-
22-005	42	22	44.1	66.1	88.1	110.2	207.4	444	-	-
32-065	46	0	0	0	11.3	17	-	-	-	-
33-151	43	1	2	3	4	5	516	-	-	-
38S-001	48	0	0	0	18.6	92.8	167	-	-	-
38S-258	38	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
48C-100	41	5.3	10.6	15.9	20.5	34	-	-	-	-
07-056	75	0	0	0	0	16.2	20	-	-	-
16-018	61	6	12	18.1	24.2	49.7	796.3	929	-	-
17-061	70	0	0	0	0	112	140	-	-	-
18-104	60	4.2	8.4	12.6	16.8	21	25.2	29.4	33.6	86
19-374	80	0	0	0	0	0	0	-	-	-
21-074	58	5.7	11.4	17.1	22.8	28.6	34.3	40	45.7	978
22-002	59	19.6	39.2	58.8	78.4	98	122	-	-	-
22-354	71	14.4	28.8	43.2	57.6	72	68	-	-	-
24-211	55	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
31-101	70	0	0	0	0	0	0	0	-	-
33-150	53	10.9	21.8	32.7	43.6	134.7	385	-	-	-
33-175	57	17.7	35.4	53.1	70.8	88.5	325.3	-	-	-
38S-002	59	0	0	0	0	19.6	44	-	-	-
09-044	100	53.6	107.3	160.9	215	443	775	-	-	-
28-011	110	0	0	0	0	0	0	0	0	-
30-208	130	0	0	0	0	0	0	0	0	-
33-148	110	0	0	0	0	11	33	-	-	-
33-149	130	1.2	2.4	3.6	4.8	410	767	-	-	-
34-033	125	21.2	42.4	63.6	84.8	106	127.2	148.4	169.6	401.2
SUM		314.3	628.6	942.9	1257.2	1676.2	2234.4	2979.8	3971.9	9465.2
AVG ALL		9.5	19.0	28.5	38.0	52.3	70.8	93.8	125.8	281.4
AVG. CC<=50		10.6	21.2	31.8	42.4	56.6	75.5	100.7	134.1	311.4
AVG. 50<CC<=100		5.1	10.2	15.3	20.4	27.1	36.3	48.1	63.7	155.8
AVG. CC>=100		12.7	25.4	38.0	50.8	67.0	89.1	116.6	154.5	379.8

Table E-2
Average Rate of Deterioration Calculations

Site	Cover	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51
03-039	42	0.0	0.0	11.9	36.0							
03-069	29	13.6	27.1	40.7	54.3	392.5	908.0					
03-263	42	2.8	17.4	26.5	182.4							
06-039	39	0.0	0.0	0.0	6.1	11.0						
06-120	40	0.0	0.0	0.0	0.0							
07-039	31	0.8	1.8	2.4	3.2	17.6	360.0					
07-069	43	0.5	1.0	1.5	2.0	2.5	3.0	5.0				
07-070	44	1.7	3.4	5.1	6.8	8.1	30.0					
07-071	42	0.0	0.0	0.0	0.0	0.0	1.1	33.0				
09-042	45	0.0	0.0	0.0	0.0	0.0						
11-019	42	6.2	12.4	18.6	24.8	31.0	37.2	43.4	221.4	945.0		
12-080	40	4.4	8.8	13.2	17.6	22.0	26.4	31.0	300.0			
16-103	36	0.0	0.0	0.0	0.0	0.0	0.0	0.0		188.2	294.0	
16-114	44	0.0	0.0	0.0	0.0	15.7	61.0					
16-155	40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19-229	35	0.0	0.0	0.0	0.0	30.0						
19-369	49	2.0	4.0	6.0	8.0	10.0	120.0	275.0				
19-373	46	0.0	0.0	0.0	0.0	43.0	100.0					
26-061	45	2.0	4.0	6.0	8.0	479.0						
26-081	31	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
29-056	41	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
31-210	47	2.5	5.0	7.5	10.0	170.0						
31-232	50	0.0	0.0	0.0	102.4	288.0	320.0					
31-241	35	0.0	0.0	0.0	0.0	0.0						
31-242	45	0.0	0.0	0.0	1.1	2.0						
31-243	30	0.0	0.0	0.0	0.0	0.0						
33-176	43	0.0	0.0	0.0	0.0	0.0						
33-177	48	2.1	5.0	7.5	10.0	13.5	300.0					
35-005	38	11.0	22.0	33.0	44.0	55.0	66.0	372.0				
37-194	33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
37-31163	49	1.6	3.2	4.8	5.5	21.8	29.0					
37-31168	41	2.1	4.2	6.3	7.0	21.0	28.0					
37-333	39	1.6	3.2	4.8	6.4	180.0						
48C-008	43	6.8	13.6	20.4	27.0	252.0						
48C-011	39	21.5	43.0	64.5	86.0	249.0	1186.0					
48C-023	44	12.9	25.8	38.7	51.6	105.6	266.0					
48C-030	35	22.6	45.2	67.8	90.4	130.4	187.4	450.0				
48C-038	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
05-050	64	0.0	0.0	7.5	65.6	75.0						
07-023	37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	48.0		
07-054	75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10-160	35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	260.0	
11-164	79	0.0	0.0	0.0	0.0	0.0	14.2	17.0				
11-174	80	0.0	0.0	0.0	0.0	0.0	18.3	22.0				
11-257	68	0.0	0.0	0.0	0.0							
13-058	95	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0	80.0
13-039	53	24.7	49.4	74.1	98.8	123.5	148.2	172.9	178.0	156.0		
17-058	89	0.0	0.0	0.0	0.0	0.0	0.0	59.0	167.0			
17-065	63	0.0	0.0	0.0	0.0	0.0						
17-074	80	0.0	0.0	0.0	0.0	200.0						
17-077	69	0.0	0.0	0.0	0.0	0.0						
23-149	63	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
23-122	63	4.5	9.0	13.5	18.0	22.5	185.0					
26-080	53	0.0	0.0	0.0	0.0	0.0						
31-102	70	0.4	0.8	1.2	1.6	2.0	31.7	130.0				
31-243	68	10.6	21.2	31.8	194.1	699.0						
36-034	70	0.0	0.0	0.0	0.0	10.0						
415-074	80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	485.0	875.0	
43-079	73	7.0	14.0	21.0	28.0	35.0	55.0	333.0				
43-115	65	15.6	31.2	46.8	62.4	75.5	233.0					
44-023	75	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
44-065	51	3.6	11.2	16.8	22.4	47.6	160.0					
44-164	57	1.3	2.6	3.9	4.4	13.0						
45B-003	53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.5	83.0	
48B-027	70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
07-024	130	3.8	7.6	11.4	15.2	19.0	22.8	60.8	1000.0			
31-126	105	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.6	57.0
SUM		29.4	41.7	64.6	130.3	412.8	527.7	1349.7	1872.8	1832.8	1300.0	1370.0
AVG ALL		3.4	6.9	10.6	22.4	72.4	130.7	70.4	133.8	183.3	197.6	45.7
AVG CC<=50		6.3	12.7	16.5	29.8	92.1	207.5	95.5	132.3	576.6	94.1	
AVG 50<CC<=100		3.0	5.9	9.1	20.8	56.8	50.0	31.2	43.9	97.1	212.0	40.0
AVG CC=100		1.9	3.8	5.7	7.6	9.5	11.4				14.6	57.0

Table E-3
Average Rate of Deterioration Calculations